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MASTER

RADIOECOLOGY OF SOME NATURAL ORGANISMS AND SYSTEMS IN COLORADO

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Department of Radiology
and Radiation Biology
Colorado State University
Fort Collins, Colorado

DISCLAIMER

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DEPARTMENT OF RADIOLOGY AND RADIATION BIOLOGY
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO

TO: U. S. Atomic Energy Commission
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RADIOECOLOGY OF SOME NATURAL ORGANISMS AND SYSTEMS IN COLORADO

FOR THE PERIOD: January 1, 1969 - December 31, 1969

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The following persons deserve recognition for their assistance during the past year: for consultation on the grassland study, R. E. Bement, R. L. Dix, D. N. Hyder, J. F. McCormick, T. O. Thatcher, and R. T. Ward; for consultation on the pika study, N. R. French and R. M. Hansen; for consultation on the aquatic studies, T. G. Bahr, L. W. Durrell, G. E. Powers, and E. B. Reed; for consultation on the deer studies, A. E. Anderson; for administrative and general technical assistance, A. H. Dahl; for field and laboratory assistance, A. W. Alldredge, C. L. Bauman, J. Doerges, G. C. Inyamah, G. E. McIntyre, D. J. Mumm, V. Roberts and C. R. Throckmorton; for instrumentation maintenance, J. L. Harness; and for secretarial assistance, P. Davis, M. Hakonson, M. Mulvihill, N. Schreckhise, and J. Trippel.

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I. SUMMARY

I. Summary

The general objective of this research is to provide information on the behavior of radionuclides in, and radiation sensitivity of, selected organisms and natural systems in Colorado. Components of several kinds of natural systems, including alpine tundra, montane forests, shortgrass plains, and freshwater lakes and streams are currently under investigation by this laboratory. This research is being conducted primarily by graduate students and faculty members in the Department of Radiology and Radiation Biology at Colorado State University.

This report summarizes project activities and major findings during the calendar year 1969. During this period, two separate investigations were completed. A study on radioiodine retention in mule deer was completed by C. S. Gist who submitted the results as a M.S. Thesis. A. F. Gallegos submitted a Ph.D. Dissertation on the behavior of ^{134}Cs in a montane lake ecosystem.

Significant progress was made on several other comprehensive studies during 1969. Several captive mule deer bucks were dosed with ^{85}Sr, ^{90}Sr and ^{45}Ca by R. G. Schreckhise to investigate uptake, retention and translocation of these elements. Numerous improvements in the deer handling facilities were also made. Two one-acre pika colonies were successfully established by O. D. Markham and one study on the effect of population density on the pikas' response to radiation was conducted. Irradiation of a shortgrass plains plant community was initiated in April by L. Fraley. Significant changes in the structure of the community have been recorded throughout the year. L. L. Cadwell established a trapping grid for arthropods within the grassland radiation field and evaluation of early results is in progress.

II. RADIONUCLIDE STUDIES WITH MULE DEER

II. A. Radioiodine Retention in Mule Deer

C. S. Gist, A. W. Alldredge and F. W. Whicker

This work is summarized in the following abstract of a M.S. Thesis, entitled "Iodine-131 Retention in Mule Deer" that was submitted by C. S. Gist to Colorado State University in June, 1969:

Mule deer accumulate significant quantities of ^{131}I following many types of nuclear explosions and certain reactor activities. In order to understand the mechanisms of accumulation, captive deer were given acute oral doses of ^{131}I which was subsequently assayed in-vivo with a scintillation counter so that uptake and retention parameters could be determined. Counting data were fit to various models by statistical techniques. Uptake and retention were examined in relation to sex, age and season.

Measurable ^{131}I appeared in the thyroid gland within a few hours and maximum levels occurred from one to four days following dosing. After the thyroid reached maximum accumulation, the ^{131}I was lost from the gland with an effective half time of 4.5 to 8 days. The shorter half times were found in winter in juvenile deer. Mean thyroid uptake was 24 percent with higher values occurring in winter.

Based on these parameters, it was estimated that the ^{131}I concentration in the deer thyroid may exceed 850 times the nuclide concentration in deer forage.

II. B. Strontium and Calcium Metabolism in Mule Deer

R. G. Schreckhise, A. W. Alldredge and F. W. Whicker

A previous study by Schultz[1] to determine the feasibility of using antlers for approximating ^{90}Sr body burdens in deer and current fallout levels demonstrated a significant correlation between ^{90}Sr levels in the mandible and antler in white-tailed deer. Schultz further reported that due to translocation of ^{90}Sr from skeleton to antler during antler formation, the ^{90}Sr content is not a good source for current fallout data without further studies on calcium and strontium metabolism as related to antler development.

This study was initiated to investigate the effects of age, season and sex on strontium and calcium kinetics (uptake, retention, and translocation) in the mule deer (Odocoileus hemionus hemionus).

Because of the hormonal changes associated with antler growth in the male and gestation and lactation in the female, calcium and strontium metabolism may vary with season[2]. Age also affects Ca-Sr kinetics as younger deer apparently have faster Ca-Sr turnover rates and higher fractional uptakes[3]. Calcium-strontium kinetics in doe-fetus and doe-fawn relationships might be important factors influencing ^{90}Sr levels in very young deer.

Uptake, retention and translocation parameters are being studied by giving acute oral doses of ^{45}Ca, ^{85}Sr and ^{90}Sr to deer at various times of the year and making subsequent periodic urine and fecal collections, whole body counts and analyzing antlers.

The facilities and deer herd used are essentially the same as those described by Gist[4] and Hakonson[5]. Techniques and procedures were developed to facilitate working with antlered bucks. A metabolic cage (Fig. II. B. 1.) was constructed which enabled complete urine and fecal collections. The cage is 8 feet square and 6 feet tall. The sides are of 2 x 4 inch welded wire with a 16-inch strip of sheet metal around the bottom of the cage which helps confine urine and feces within the cage. The open sides enable the penned deer to maintain visual contact

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[1] Schultz, V. 1965. Comparison of strontium-90 levels between antler and mandible in white-tailed deer. J. Wildlife Mgmt. 29(1):33-38.

[2] Cowan, R. L. et. al. 1969. Deer antler growth ideal test for study of bone metabolism. Science in Agriculture. 17(1):3.

[3] Farris, G. C. 1967. Factors influencing the accumulation of strontium-90, stable strontium and calcium in mule deer. Ph.D. Dissertation. Colorado State University, Fort Collins. 189 p.

[4] Gist, C. S. 1969. Iodine-131 retention in mule deer. M.S. Thesis. Colorado State University, Fort Collins. 75 p.

[5] Hakonson, T. E. 1967. Tissue distribution and excretion of ^{134}Cs in the mule deer. M.S. Thesis. Colorado State University, Fort Collins. 121 p.

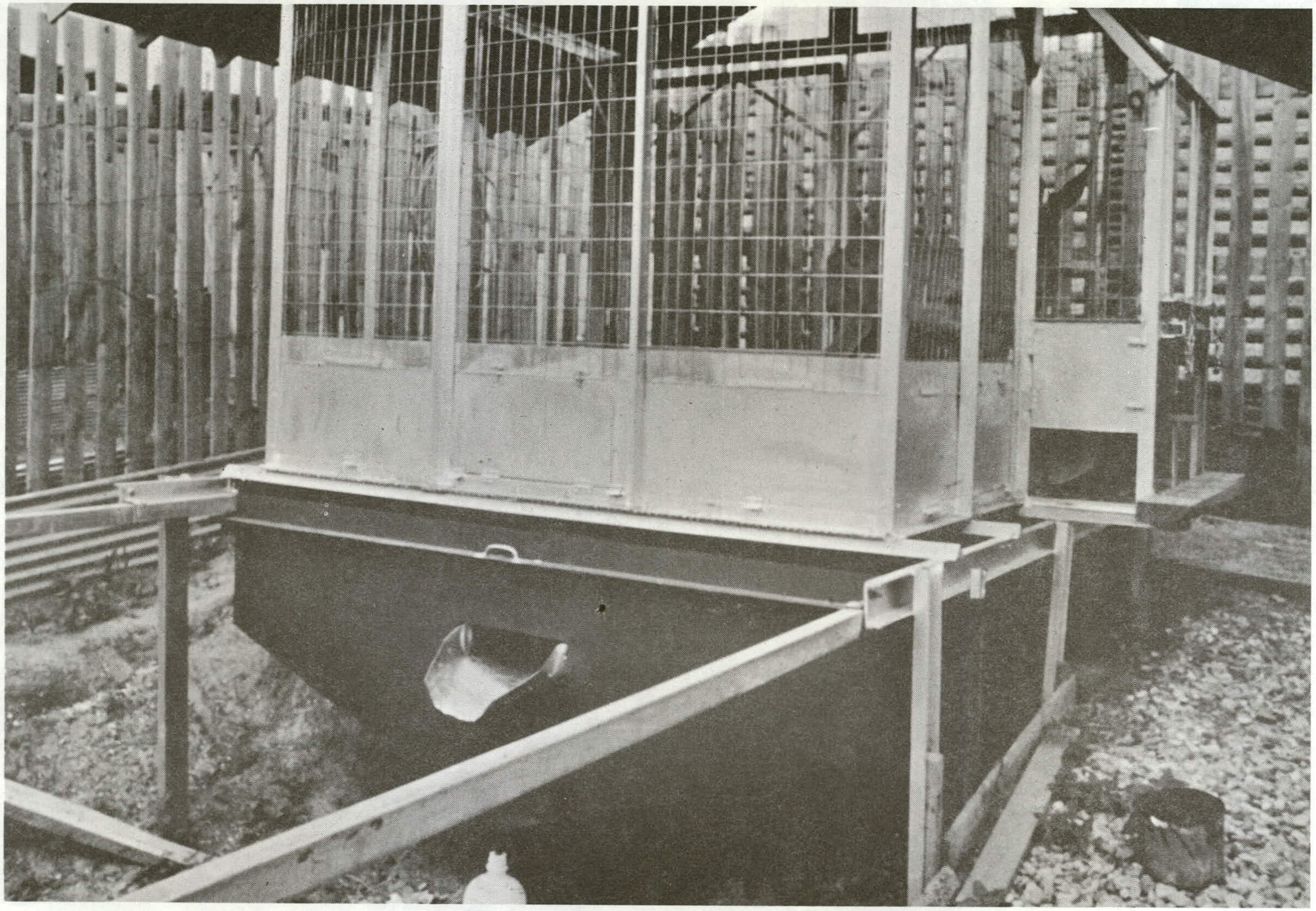

Fig. II. B. 1. Metabolic cage designed to collect and separate urine and feces from antlered deer.

with other deer which appears to promote calmness and normal food consumption. The floor is #9-3/4 inch expanded metal which allows the urine and feces to pass through for collection in a large pan. The inside surface of the collection pan was painted with an epoxy-base paint for ease of cleaning and decontamination. The bottom of the collection pan slopes downward to a collection point. Urine is collected in a bottle through a spout at the low point of the collection pan. The pan contains a wire screen which effectively separates urine from feces. The entire collection pan can be rolled out on tracks from underneath the cage for collection of the feces and cleaning the pan.

The metabolic cage does not appear to have adverse effects on the deer. Daily feed and water consumptions were recorded and the values did not differ significantly from those of deer in larger pens.

Periodic whole body counting was conducted with a 3 x 3 inch NaI(Tl) detector attached to a Ludlum 20-A single channel analyzer-scaler. The deer were confined in an outside chute with the detector 8 feet away in a small shed. This arrangement caused difficulties as the crystal and scaler were exposed to changing air temperatures which seriously affected the counting efficiency of the detector-scaler. A new building was constructed to house both the counting chute and the detector-scaler for consistent temperature control. The counting chute (Fig. II. B. 2.) is designed to facilitate whole body counting antlered bucks and still keep movement at a minimum. The floor of the chute rests on a platform scale which enables weighing of the deer. The ½ inch plywood sides prevent injury to the deer and keep gamma absorption at a minimum. The interior was painted with forest-green lead-free epoxy-base paint for cleaning and decontamination purposes. Sliding doors are positioned at both ends of the counting chute.

Five male deer, ages 1-4 years, were given acute oral doses of approximately 100 μCi ^{45}Ca, 1.0 mCi ^{85}Sr and 10 μCi ^{90}Sr in the summer during various stages of antler development. Each buck was confined in the metabolic cage and complete excreta collection and whole body counts were made daily for two weeks following ingestion. The bucks were then placed in the large pens with other deer. Whole body counts were then made at progressively longer time intervals.

The results of whole body counting of a yearling buck is illustrated in Fig. II. B. 3. The relative activity of ^{85}Sr retained in the deer as a function of time is expressed as a fraction of the first count taken ten minutes after the acute oral ingestion of the isotopes. The results of the whole body counts of the five deer along with those obtained by Farris and Whicker[6] in which three bucks, ages 1-3 years, were given acute intravenous injections (I.V.) of 1-2 mCi ^{85}Sr are given in Table II. B. 1.

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[6] Farris, G. C. and F. W. Whicker. 1969. Translocation of ^{85}Sr from skeleton to antler in mule deer. In Seventh Annual Progress Report to the U. S. Atomic Energy Commission on Contract AT (11-1)-1156, Department of Radiology and Radiation Biology, Colorado State University, Fort Collins.

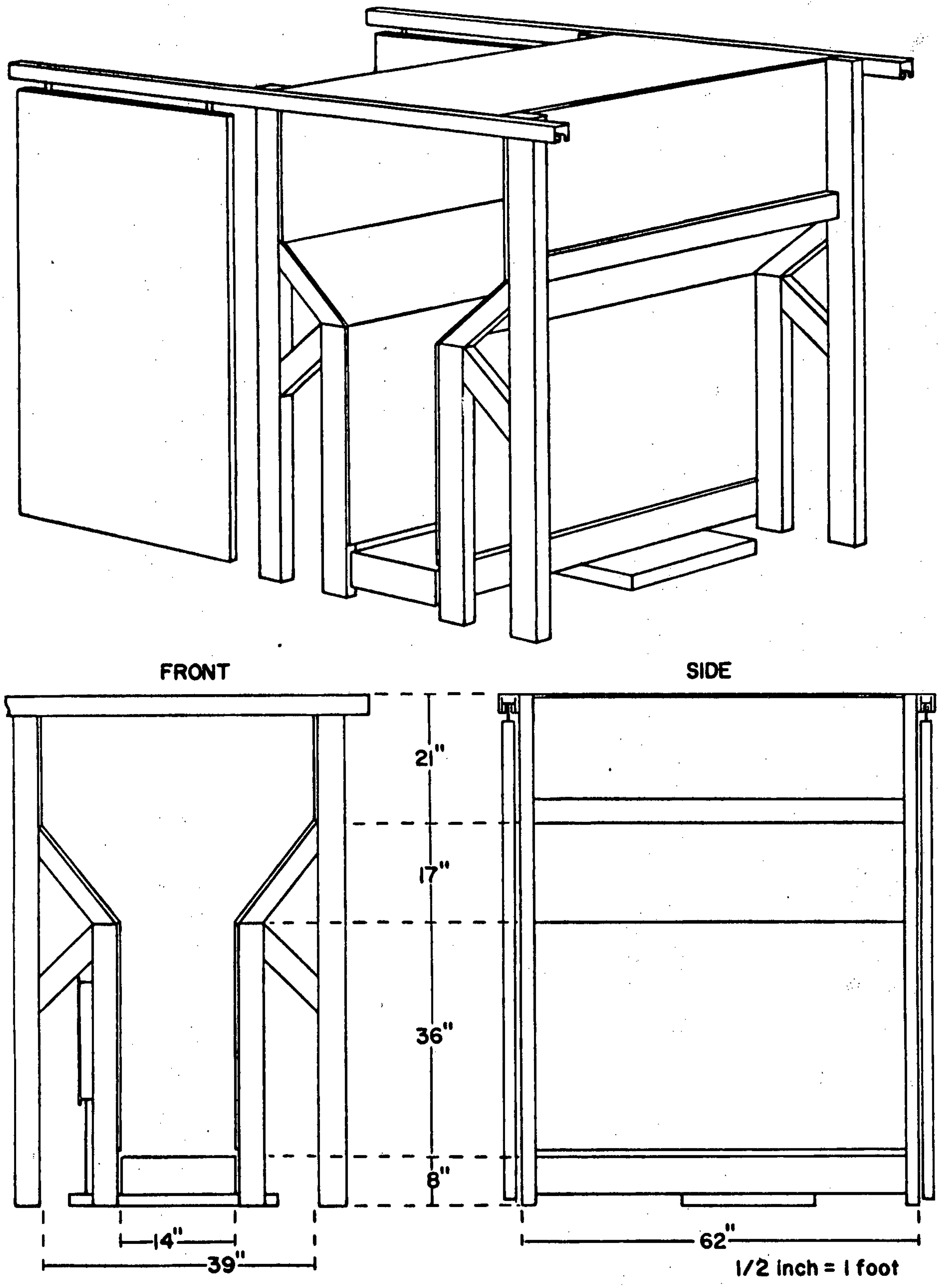

Fig. II. B. 2. Counting chute for measuring ^{85}Sr retention in antlered deer.

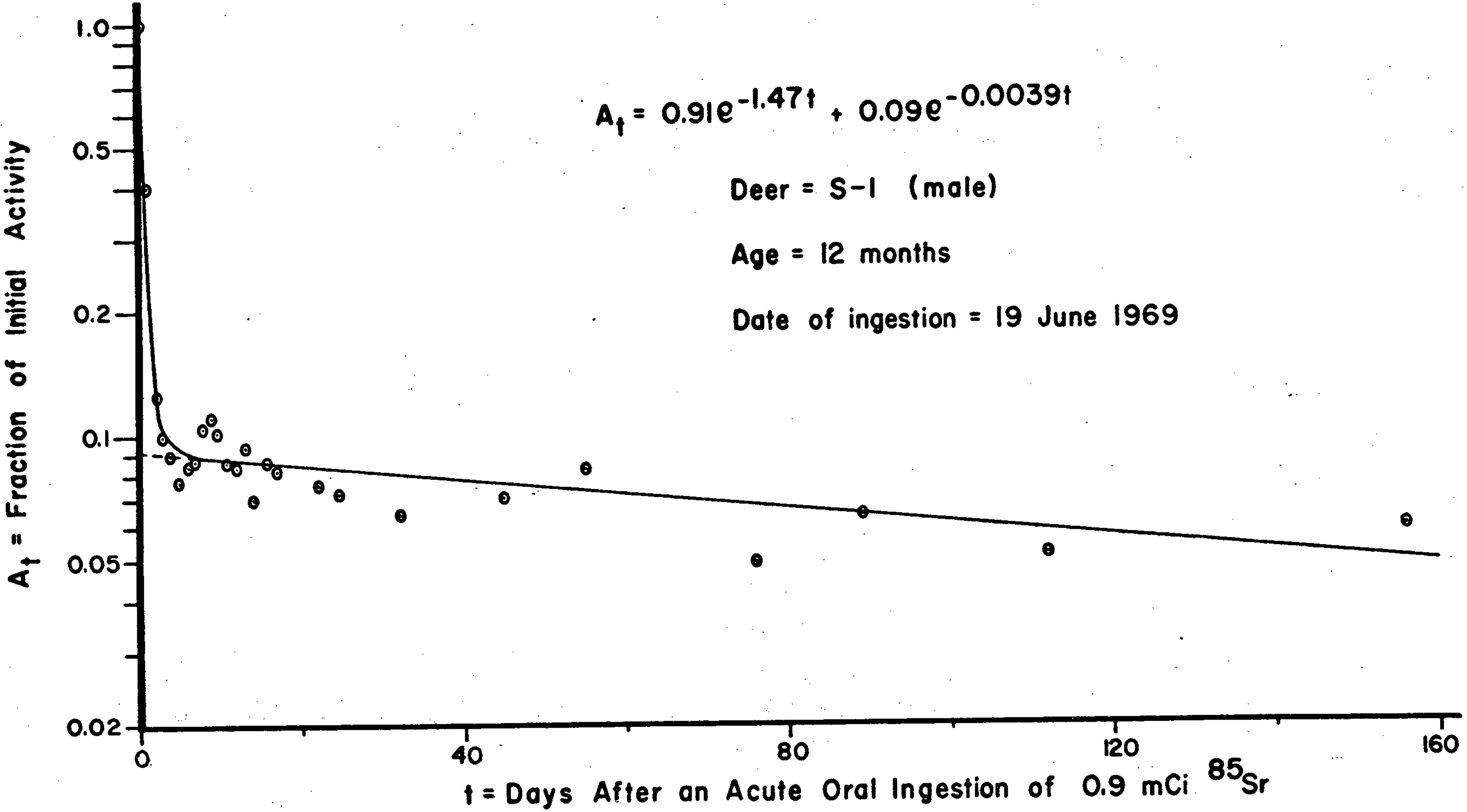

Fig. II. B. 3. Total body retention of an acute oral dose of ^{85}Sr as determined by whole body counting.

Table II. B. 1. Fractional Uptakes and Biological Half-Lives of ^{85}Sr in Male Mule Deer Dosed at Various Stages of Antler Development as Measured by Whole Body Counting for Three to Five Months After Ingestion.

Deer	Age at Time of Dosing (Months)	Weight (Kg)	Date of Dosing	Method	Antler Length at Time of Dosing as a Fraction of Final Antler Length	Fractional Uptake Represented by Long Component	Biological Half-Life of Long Components (Days)
F-3	10	27.2	4/7/68	I.V.	0	0.388	163
S-1	12	45.4	6/19/69	Oral	0.40	0.090	176
F-2	21	82.2	3/25/68	I.V.	0	0.700	276
S-2	25	56.8	7/6/69	Oral	0.48	0.041	181
S-3	25	45.4	7/30/69	Oral	0.83	0.088	140
S-4	26	56.8	8/14/69	Oral	0.95	0.054	288
F-1	33	--	3/25/68	I.V.	0	0.822	108
S-5	51	90.8	9/2/69	Oral	1.0	0.152	144

The values obtained for fractional uptakes and biological half-times are very preliminary because of the short observation period (three to five months). The biological half-lives of the long components were not significantly different ($P < 0.05$). No attempt was made to compare or evaluate these values with respect to age, time or weight differences. The variations in fractional uptakes are primarily due to the methods of administering the doses (I.V. versus oral ingestion).

Farris[7], from a method described by Rivera[8], indirectly estimated biological half-lives for ^{90}Sr in deer of 1.7 and 9.7 years for age groups 7-18 and over 55 months, respectively. Rundo[9] reported that the retention of ^{85}Sr in adult humans is described by a three component curve with half-lives of 2.68, 19.2 and 750 days. Because of the relatively short physical half-life of ^{85}Sr (65 days), whole body counting the deer is limited to six to eight months after ingestion. This is the primary reason ^{90}Sr was also given. By making monthly excreta collections over a longer time period and analyzing for daily ^{90}Sr excretion, one will be able to better approximate biological half-lives and fractional uptakes. From these long term studies one might observe half-lives approaching those reported by Farris. We might also observe that Sr kinetics in deer can be expressed by three component retention curves. If so, the half-time values in Table II. B. 1. may not represent the long component. Strontium half-times might be a function of season and the values in Table II. B. 1. may be due to physiological variations associated with antler development. These and other questions can only be answered after longer term observations are completed.

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[7] Farris, G. C. 1967. Op. Cit.

[8] Rivera J. 1964. Strontium turnover rates in human bones. Radiol. Health Data. 5:98-99.

[9] Rundo, J. 1967. Kinetics of strontium-85 deposition in the skeleton during chronic exposure. In Strontium Metabolism, pp. 131-138. Academic Press, London.

II. C. Cesium-137 and Iodine-131 in Mule Deer, 1969

F. W. Whicker and O. D. Markham

Four deer were collected in 1969 from the Cache La Poudre drainage in north central Colorado for radionuclide determinations. Two animals were collected from the summer range and two from the winter range. Muscle tissues were assayed for ^{137}Cs, thyroids were scanned for ^{131}I, and metacarpals were saved for future determination of ^{90}Sr.

Relatively little ^{137}Cs has been injected into the atmosphere since 1963 and therefore, annual measurements since that time indicate the degree of persistence of the nuclide in the deer food chain. Levels of ^{137}Cs in deer muscle were readily detectable in 1969 with values ranging between 130 and 630 pCi/Kg fresh tissue (Table II. C. 1.). Contrary to results obtained in 1968, deer collected from the summer range in 1969 contained more cesium than winter range animals. Of course, this observation may give a false impression relative to the deer population because of the inadequate sample size.

None of the deer thyroid glands collected in 1969 contained measurable ^{131}I.

Table II. C. 1. Concentrations of ^{137}Cs and ^{131}I in Mule Deer Collected From the Cache La Poudre Drainage, Colorado 1969.

No.	Date	Sex	Age Class	Location Sec T R	Elevation (feet)	^{137}Cs pCi/Kg Fresh Muscle	^{131}I pCi/g Fresh Thyroid
69-1	7-2-69	F	Mature	10 6N 75W	10,200	630	N.D.*
69-2	7-2-69	F	Mature	10 6N 75W	10,200	530	N.D.
69-3	12-19-69	M	Mature	2 8N 72W	7,100	130	N.D.
69-4	12-26-69	M	Mature	32 9N 72W	7,450	174	N.D.

*N.D. - Not detectable

III. RADIONUCLIDE STUDIES OF AQUATIC SYSTEMS

III. A. Radiocesium Kinetics in a Montane Lake Ecosystem
A. F. Gallegos and F. W. Whicker

This work is summarized in the following abstract of a Ph.D. Dissertation, entitled "Radiocesium Kinetics in the Components of a Montane Lake Ecosystem" that was submitted by A. F. Gallegos to Colorado State Univeristy in December, 1969:

Combined laboratory aquarium and lake observations with important components in the East Twin Lake ecosystem were utilized in the synthesis of a radiocesium kinetics compartment model for predicting the build-up of this radionuclide in the tissues of fish and other components at the lake. Analysis of Cs-137 build-up data in fish obtained from the lake by a postulated biological model showed that the required daily intake of radiocesium was about ten times greater than that obtained from their food sources. Close to 80 percent of the diet of rainbow trout in ETL consisted of Gammarus lacustris, while most of the remainder consisted of Daphnia pulex. Sediment uptake by fish is postulated as the major cause of radiocesium build-up in fish at ETL, as 20 to 40 percent of the absorbed radiocesium is removed by the gut of rainbow trout. Qualitative identification of feldspars and quartz in the stomach and intestinal contents of rainbow trout from ETL also lends support to this theory.

In addition to the compartment model synthesis for various components at ETL, a chronic ingestion model was also derived for rainbow trout at ETL utilizing the Cs-137 build-up data, Cs-134 excretion experiments in rainbow trout, and Cs-134 tissue distribution studies on these fish.

The effect of temperature and weight of fish on the retention of radiocesium by rainbow trout was studied in a laboratory aquarium system designed to have refrigeration capacity, and to provide for treatment of solid and dissolved organic matter derived from fish wastes. A weight/temperature interaction term was shown to affect the overall excretion pattern of radiocesium as a function of time. Retention half-times of the long component in these fish were observed to be affected not only by a weight/temperature interaction term, but also by the percent weight increase of the fish during the test interval.

Laboratory experiments with Gammarus lacustris in aquaria contaminated with Cs-134 showed that the concentration factor of these organisms at equilibrium was largely dependent on the water radiocesium concentration.

Limnological studies at ETL provided most of the necessary information required for proper description of this ecosystem in terms of radiocesium movement and pool size estimates. The total Cs-137 inventory of ETL was estimated to be 10 mCi.

III. B. Cesium-137 in Trout During 1969

F. W. Whicker, W. C. Nelson, A. F. Gallegos and T. E. Hakonson

During 1969 trout were sampled from three mountain lakes and analyzed for ^{137}Cs (Table III. B. 1.). The lakes reported here have been sampled each fall for the past several years so that temporal trends in ^{137}Cs concentrations might be compared. Snow and Agnes are classified as alpine lakes (elevation greater than 3200 meters) and are relatively low in dissolved nutrients with conductivities ranging 10 to 27 micromhos. East Twin Lake is in the montane zone (elevation 2880 meters), is of the semi-drainage, dyseutrophic type; and its conductivity ranges from 50 to 97 micromhos.

The decreasing trend in ^{137}Cs concentrations in trout from Snow and Agnes lakes continued into 1969 (Fig. III. B. 1.). Trout in East Twin Lake, however, do not appear to be decreasing in the ^{137}Cs burden. Data in Fig. III. B. 1. for East Twin do not appear to entirely justify this statement, however, trout caught in 1967, 68 and 69 were apparently not in the lake for a sufficient length of time to have been in equilibrium with the dietary sources. Buildup data from 1967-68 indicated that ^{137}Cs equilibrium values in the trout would approach 3000 pCi/Kg fresh muscle. The trout from Snow and Agnes lakes had been in the lakes at least several years and equilibrium conditions probably prevailed.

It appears that the ^{137}Cs levels in trout from Snow and Agnes lakes are governed by recent fallout deposition rates, whereas the cumulative ^{137}Cs budget of the sediment of East Twin Lake controls the equilibrium concentrations in trout. Gallegos[1] concluded that involuntary ingestion of sediment by trout in East Twin Lake accounts for about 80 percent of their ^{137}Cs intake.

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[1] Gallegos, A. F. 1969. Radiocesium kinetics in the components of a montane lake ecosystem. Ph.D. Dissertation. Colorado State University Fort Collins. 342 p.

Table III. B. 1. Summary of ^{137}Cs Analyses of Trout Flesh in 1969

Lake	Collection Date	Species	No. Fish	No. Pooled Samples	Mean Length (mm)	Mean Weight (g)	^{137}Cs Conc.(pCi/Kg fresh)	
							Mean	S.E.
East Twin	5-24-69	Rainbow	1	1	444	1,000	2625	--
	6-17-69	Rainbow	4	4	365	785	2787	331
	10-9-69	Rainbow*	14	3	317	437	1554	193
Agnes	9-11-69	Brown	1	1	460	879	989	--
		Rainbow	1	1	316	349	428	--
		Cutthroat	5	2	325	348	512	59
		Long nosed Sucker	14	2	235	147	650	159
Snow	9-12-69	Cutthroat	18	2	167	65	1336	13

*Includes one fish planted in 1968; all others planted in 1969.

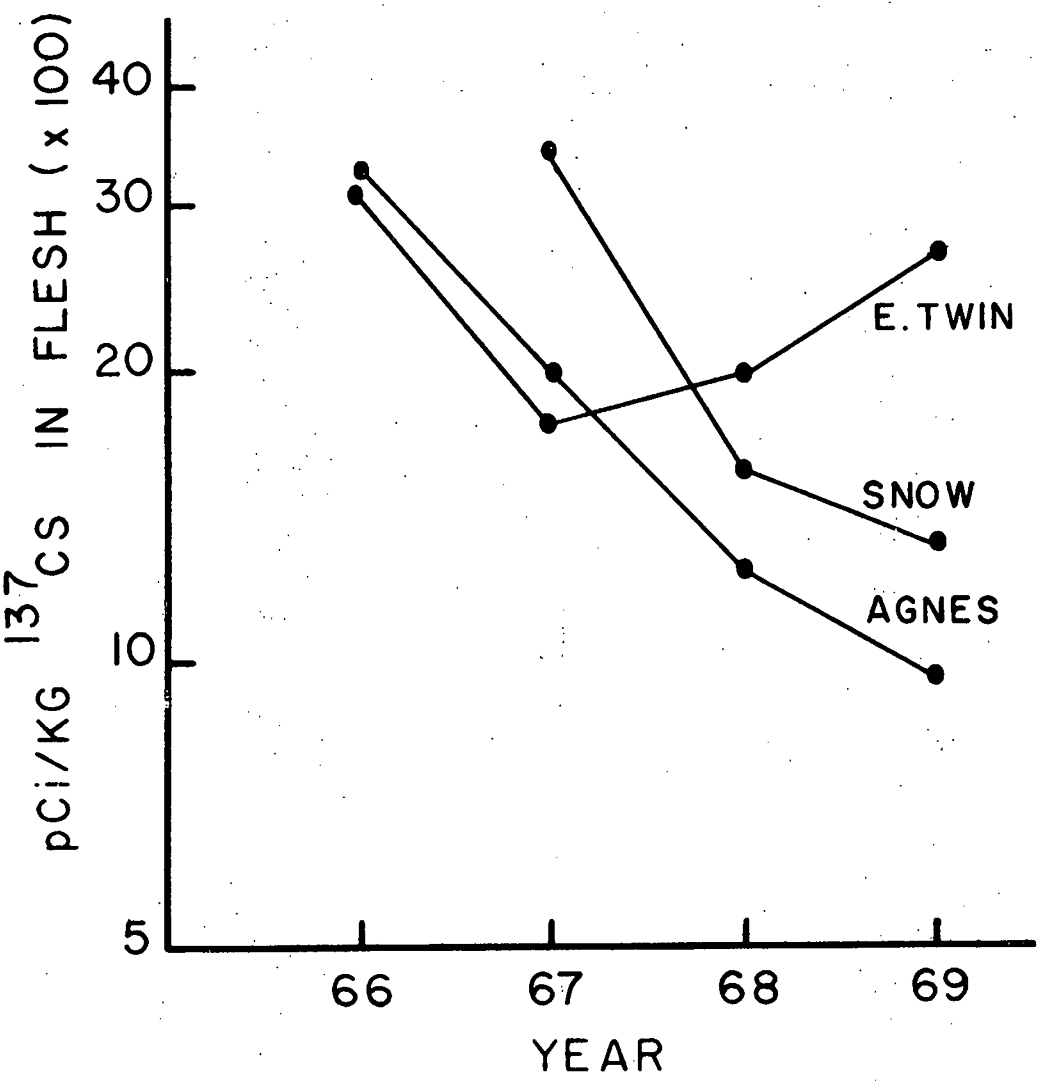

Fig. III. B. 1. Concentrations of ^{137}Cs in trout from three mountain lakes in north-central Colorado from 1966 through 1969.

IV. EFFECTS OF RADIATION AND SOCIAL STRESS ON THE PIKA

IV. Effects of Radiation and Social Stress on the Pika

O. D. Markham and F. W. Whicker

It is generally believed that social and environmental stresses can modify response to ionizing radiation in living organisms. However, little is known about the specific nature of such interactions. A previous study[1] suggested that pikas (<u>Ochotona</u> <u>princeps</u>) in the natural environment are more sensitive to ionizing radiation, in terms of the $LD50_{(30)}$, than those studied in captivity. Since pikas in captivity were individually caged, it was suggested that a synergism between radiation and social interaction in the natural environment may have contributed to the apparent difference in radiosensitivity. This experiment was designed to evaluate the effects of social interaction upon the response of pikas to ionizing radiation.

Two square one-acre areas were enclosed by rodent-proof fences (Fig. IV. 1.) similar in design to one reported by French[2]. An electrically charged single-strand wire was mounted five inches above the fence to prevent predators from entering the enclosures. In one area 15 cage-den assemblies, each consisting of an above-ground wire cage connected to an underground wire den by a wooden tunnel[1], were installed 34 feet apart in a circular pattern. The other one-acre enclosure had 31 cage-den assemblies 15.8 feet apart. All cages in both areas were 85 feet from the center of the area. A pile of rocks 18 to 24 inches high and 18 to 24 inches wide was placed approximately three feet in front of each cage entrance. Another rock pile was placed between adjacent cages but approximately 20 feet nearer the center of each area. Seven similar rock piles were distributed within 16 feet of the center of each enclosure. The rocks provided the pikas with places to hide, rest and store collected vegetation.

Pikas collected at Mount Evans, Colorado at an elevation of approximately 12,800 feet were placed in the cage den assemblies in the two enclosures. Some pikas were also placed in a complex of individual cage-den assemblies[1] in which social competition was limited to sight and smell. Water and commercial rabbit feed were provided ad libitum in all the cages throughout the experiment. Dandelions (<u>Taraxacum</u> <u>sp</u>.) were fed daily throughout the experiment to the animals in the individual cage-den complex and to the pikas in the enclosures until one week after release from their cages.

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[1] Markham, O. D. and F. W. Whicker. 1969. Radiation $LD50_{(30)}$ of pikas in the natural environment and in captivity. <u>In</u> Seventh Annual Progress Report to the U. S. Atomic Energy Commission on Contract AT (11-1)1156, Department of Radiology and Radiation Biology, Colorado State University, Fort Collins.

[2] French, N. R. 1964. Description of a study of ecological effects on a desert area from chronic exposure to low level ionizing radiation. University of California at Los Angeles. UCLA 12-532 Report on U. S. Atomic Energy Commission Contract AT (04-1) Gen-12. 27 p., typewritten.

Fig. IV. 1. One acre pika enclosure, showing cage-den assemblies, rock piles, and rodent-proof fence.

All pikas were ear-tagged[1] approximately one week prior to being released in the enclosures. The animals in the two one-acre enclosures were held captive in the cages for a minimum of two weeks to permit adjustment to the cage-den assembly. The doors on the cages in the enclosures were opened over a period of two weeks permitting the animals to interact.

Pikas were free to move within the enclosures for a minimum of 12 days prior to irradiation. Ten animals from each of the two enclosures and the individual cage complex were captured by placing baited No. 1 Havahart traps in the cages. The trapped pikas were immediately transferred into 4 x 8 x 4 inch ventilated 3/8 inch plywood boxes and received 500r (560r estimated $LD50_{(30)}$ in captivity[1]) at 50r/min. from a 4430 curie ^{60}Co source. The sex and age of the irradiated and control pikas are shown in Table IV. 1.

Pikas in the enclosures were observed approximately four hours daily from early daylight to midmorning. The animals were usually active only during this period of cooler temperatures. Observations were made on the locations and activities of individual animals in each enclosure. However, a smaller percentage of chases and combats were recorded in the 31 cage area than in the 15 cage enclosure because of the greater amount of simultaneous activity. Therefore, our attempts to quantify this type of behavior in each enclosure was not successful.

If an irradiated animal was not seen during an observation period, a search was conducted in the enclosure. All but two fatalities in the 15 cage area were located the same day that the animals were not seen in the observation period. Fatalities in the 31 cage area were much more difficult to locate because of the greater number of rock piles. The presence of day-old dandelions in the cage of an individually caged pika was usually the first clue that the animal was dead.

Pikas in the two enclosures were very aggressive for the first two weeks after being released. Physical combat and repeated chases were common during this period as the animals established territories. Only four animals in the 31 cage per acrea area established territories around the cage that they were originally confined to compared with five animals in the 15 cage per acre area. During this pre-irradiation period two pikas died in the 15 cage area while eight died in the 31 cage area. During the same period no deaths were recorded among the 25 animals which were individually caged. These deaths may have resulted from the competition for territories. One pika obviously injured after fighting with another was found dead the following day. Observations of the two enclosures indicated that the fighting and chasing were more severe in the higher density area. After this initial period, the pikas continued to chase but actual physical combat eventually ceased as territories became established. The general behavior patterns after the initial period of combat was very similar to that observed in their natural habitat. Pikas were observed collecting vegetation and placing it in their cages, dens and in the rock piles.

Table IV. 1. Numbers and Description of Pikas Present in Each Area at Time of Irradiation.

	15 Cages/Acre		31 Cages/Acre		Individual Cages
	Control	Irradiated	Control	Irradiated	Irradiated
Male Adults	1	4	5	5	5
Male Subadults		2	2	1	1
Female Adults	1	3	3	3	3
Female Subadults	1	1	1	1	1
*Unsexed Adult			1		
*Unsexed Subadult			1		
TOTALS	3	10	13	10	10

*Lost Identification Tags

During the post-irradiation period, one control in the individual cages died from an injury. One control and one irradiated animal in the 15 cage area died from a larval infestation of wounds. One control in the 31 cage area died in a retagging attempt and another disappeared during this period.

The mortality data for the irradiated pikas are listed in Table IV. 2. The radiation response of pikas in the 15 cages per acre area was significantly different (0.01 level) from the expected values (individually caged pikas) by the Chi-square test, but the response was not significantly different in the 31 cages per acre area. The survival times for irradiation caused mortalities are listed in Table IV. 3. The lower mortality in the high density compared to the low density enclosure was not expected. However, after pikas died in the enclosures no attempt was made to shut the cages which were on the territory of the dead pikas. Therefore, in the 31 cages per acre area there were more cage-den assemblies per pika than in the 15 cage area since there were eight vacant cages at the time of irradiation in the 31 cage area and only two in the 15 acre area. These vacant cage-den assemblies and rock piles may have offered more places of escape for chased pikas and also there may have been more territories available per pika in the 31 cage area. This may have accounted for fewer irradiation deaths in the 31 cage area.

This experiment seems to indicate that there is a difference in the irradiation response of pikas in individual cages and pikas which are free in enclosures that simulate their natural habitat. Social interactions among the pikas in the enclosures appeared responsible for deaths prior to irradiation treatment when the animals were establishing territories. It also appears that social competition was responsible for the difference in radiation response since food and water were not limiting factors.

Table IV. 2. Comparison of the Number of Deaths of Pikas 30 Days Following an Acute Exposure to 500r from ^{60}Co in Three Areas by the Chi-square Test.

	Individually Caged (Expected)	15 Cages/Acre*	31 Cages/Acre
Number Alive	7	1	5
Number Dead	3	8	5
Chi-square Value		14.86**	1.90

* One animal not included died from non-irradiation causes.
**Significant at .01 level.

Table IV. 3. Survival Times (Days) of Fatalities in Pikas Exposed to 500r Which Were in Three Areas.

Individually Caged	15/Acre	31/Acre
10	10	12
11	9	11
20	11	14
	9	12
	9	15
	11	
	13	
	9	

V. RADIATION EFFECTS ON A GRASSLAND COMMUNITY

V. A. Radiation Effects on the Plant Community

L. Fraley and F. W. Whicker

The Gamma Field

Installation of the irradiator was completed in January, 1969. Exposure levels in the gamma field were determined by short exposures of 10 to 30 minutes each with LiF thermoluminescent dosimeters. The gamma field was mapped and sector and plot boundaries were determined and staked. Each sector subtended an arc of 46° and contained 22 macroplots (Figs. V. A. 1. and V. A. 2.). The macroplots were located such that the distance from the source was measured to the back side of each macroplot. Distances were measured at ground level, starting from a point directly below the center of the source. The distance from the source to the macroplots varied from 2 to 50 meters with the depth of each macroplot adjusted to give a nearly uniform change in exposure levels from one macroplot to the next except for the restriction that no macroplot could be less than one meter in depth. The exposure rates, measured at the back side of each macroplot, varied from 650 R/hr at two meters to 0.0078 R/hr at 50 meters (Table V. A. 1.).

The microplots, each 25 x 25 cm, were located at the back side of each macroplot along a line extending from the source out the center of each sector. Twelve microplots were located in each macroplot (except for macroplot number one which was too small), arranged in two rows of six each, one row located just in front (toward the source) of the other (Fig. V. A. 3.).

During operation of the irradiator, various sectors were shielded or open, depending on the time of year. Exposure levels were measured during the year and average values for the open and shielded sectors were determined (Fig. V. A. 4.). Also during the year, exposure levels at selected depths in the soil were determined by C. R. Throckmorten, a student in the 1969 NSF Summer Institute (Fig. V. A. 5.).

Methods

The irradiator was placed in operation by raising the source on April 3, 1969 with sectors 2, 3, and 4 open and sectors 1, 5 and 6 shielded. On May 6, 1969 sector 4 was shielded. Due to periodic lowering of the source (up to four hours per day) the net exposure for sector 4 was 32 days (770 hrs). Shielding of sector 5 (summer exposure sector) was removed on July 2, 1969 and replaced August 5, 1969, giving a net exposure of 31 days (746 hrs.). Sector 6 (late fall exposure sector) was opened December 3, 1969 and closed in early January, 1970 to give the same total exposure as sectors 4 and 5.

Density data were recorded just prior to the initiation of irradiation of each seasonally exposed sector and approximately six weeks after termination of irradiation. The data were recorded by placing a 25 x 25 cm. quadrat on permanently placed locating pins for each microplot and the number of each species was counted, except for <u>Bouteloua gracilis</u>

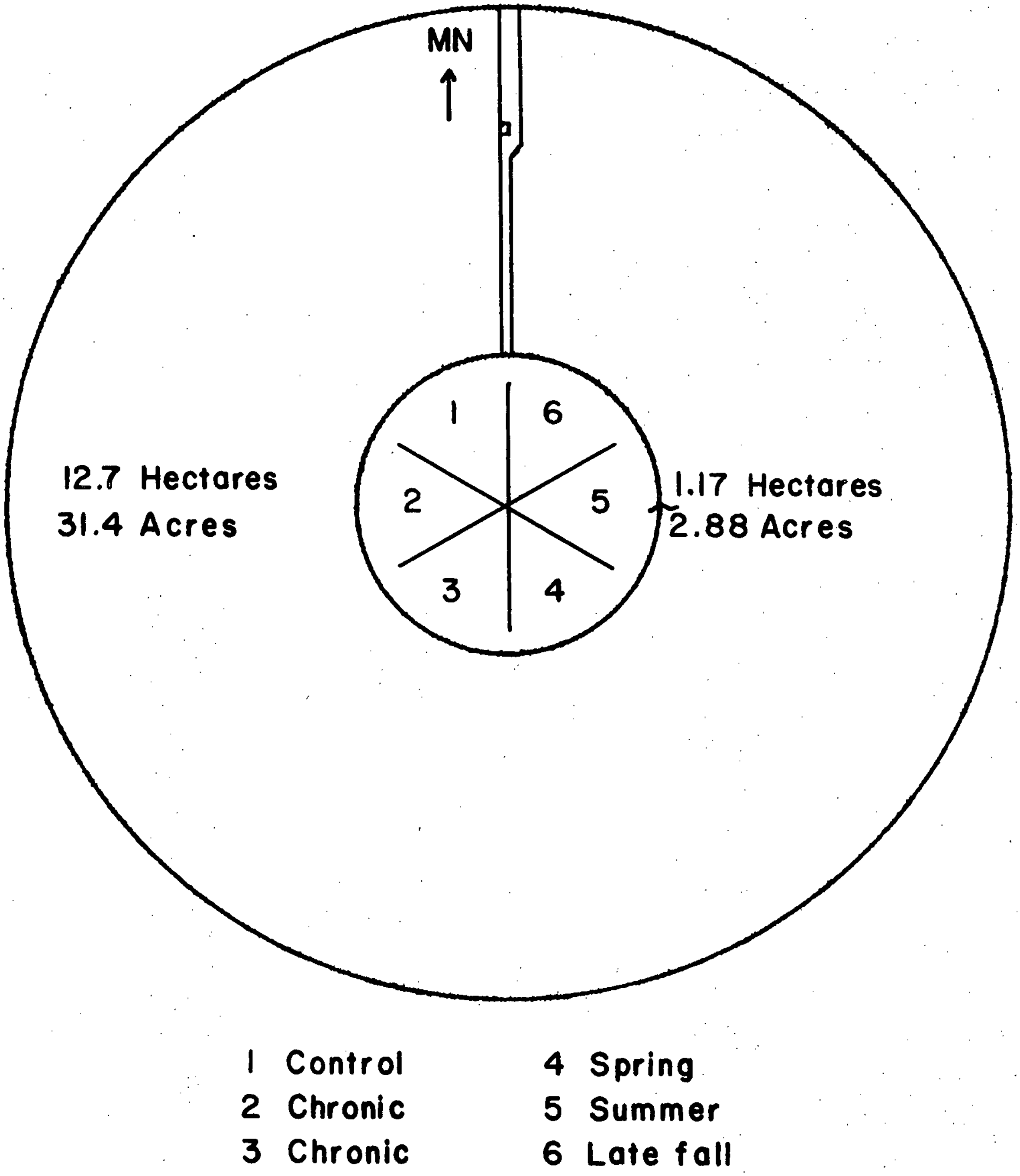

Fig. V. A. 1. Field layout of the short grass plant community study area showing outer control fence, inner security fence and sector locations.

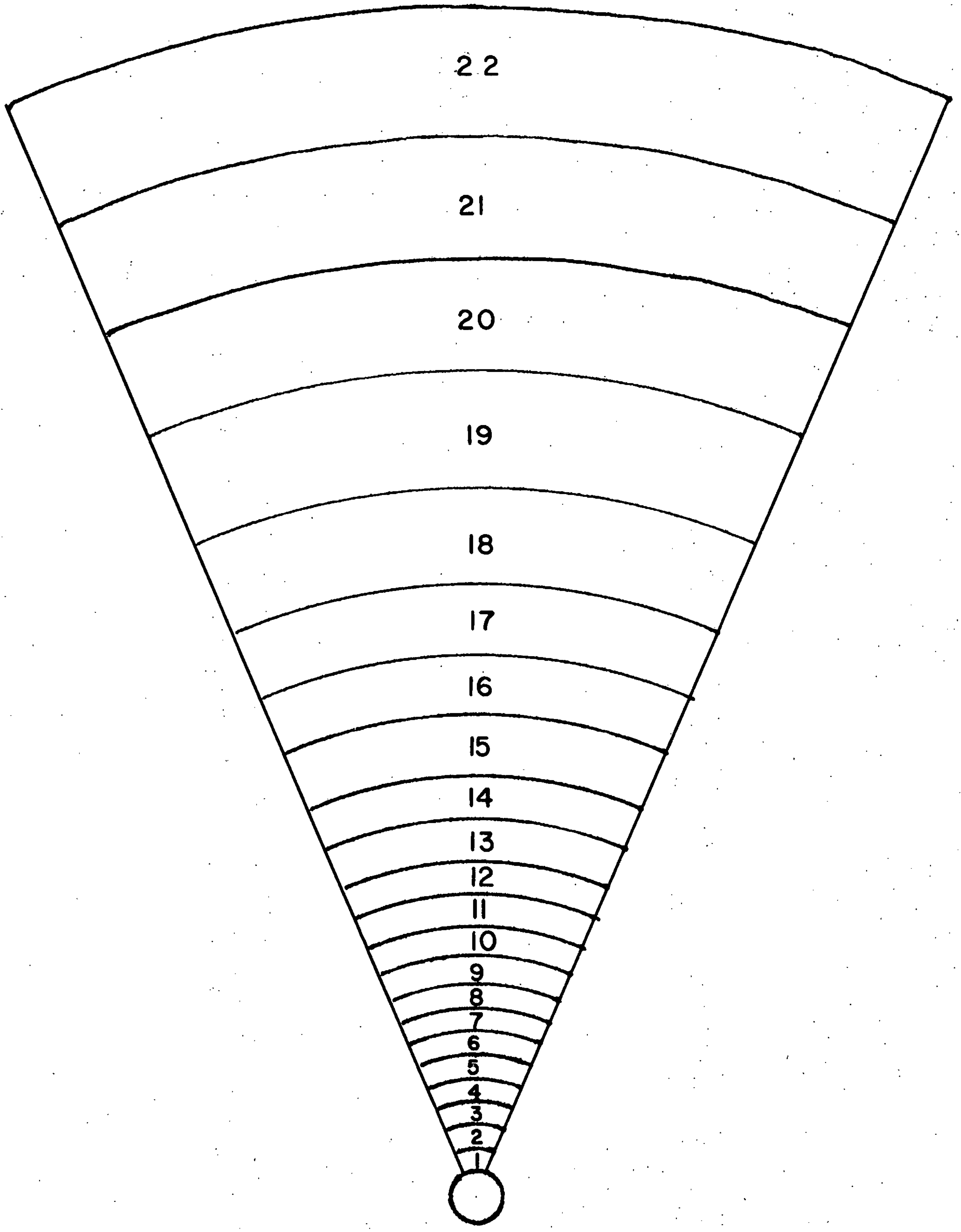

Fig. V. A. 2. Typical sector plan showing macroplot locations.

Table V. A. 1. Exposure Rate as a Function of Plot Number and Distance From the Source at the Short Grass Irradiation Study Area.

Plot Number	Distance (m)	Exposure Rate (R/hr)
1	2.0	650
2	3.0	315
3	4.0	185
4	5.0	115
5	6.0	68
6	7.0	45
7	8.0	28
8	9.0	18
9	10.2	12
10	11.5	7.2
11	12.8	4.8
12	14.2	3.4
13	16.0	2.2
14	18.0	1.3
15	20.5	0.72
16	23.0	0.41
17	26.0	0.22
18	30.0	0.10
19	35.0	0.048
20	40.0	0.024
21	45.0	0.013
22	50.0	0.0078

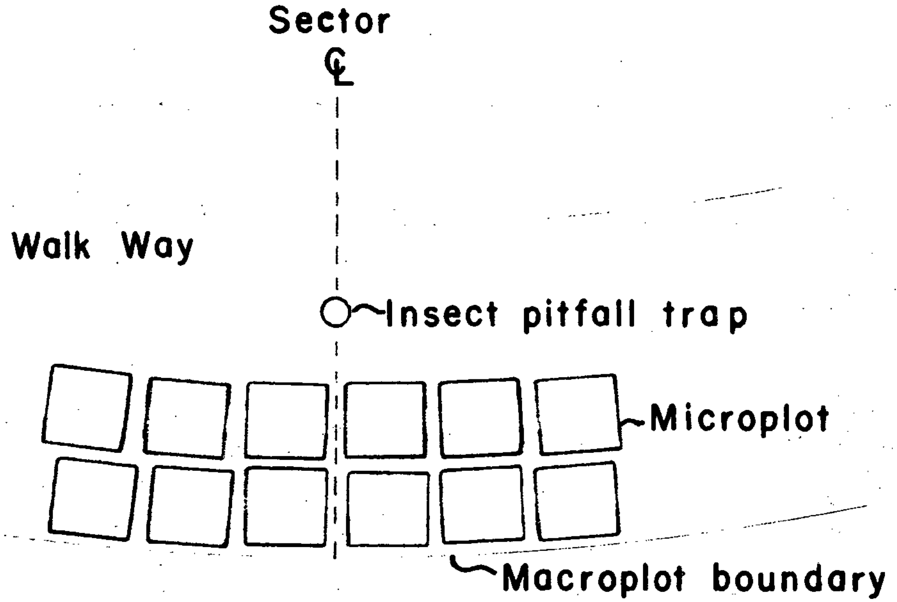

Fig. V. A. 3. Macroplot eight showing location of microplots, walkway and insect trap.

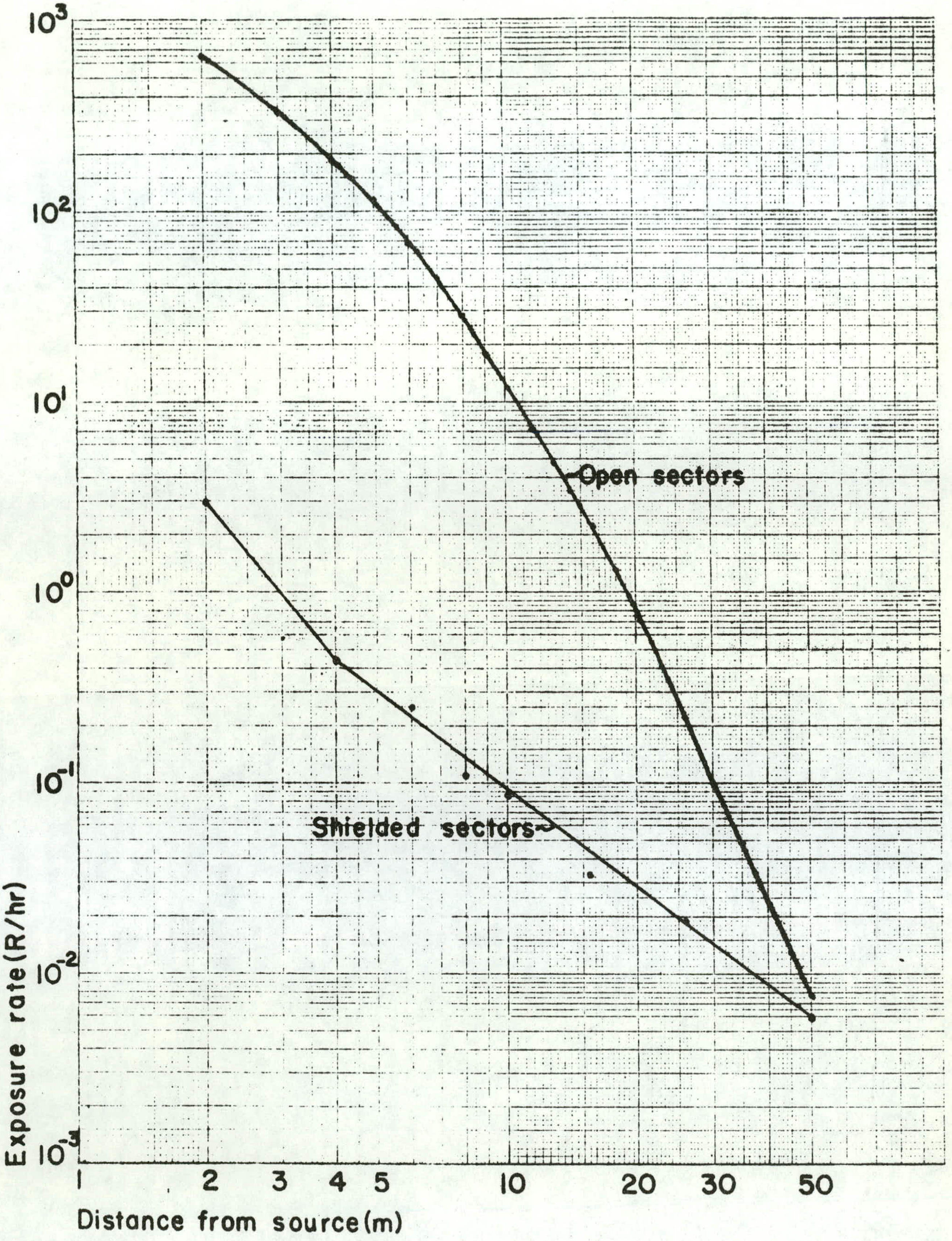

Fig. V. A. 4. Exposure rate as a function of distance for open and shielded sectors.

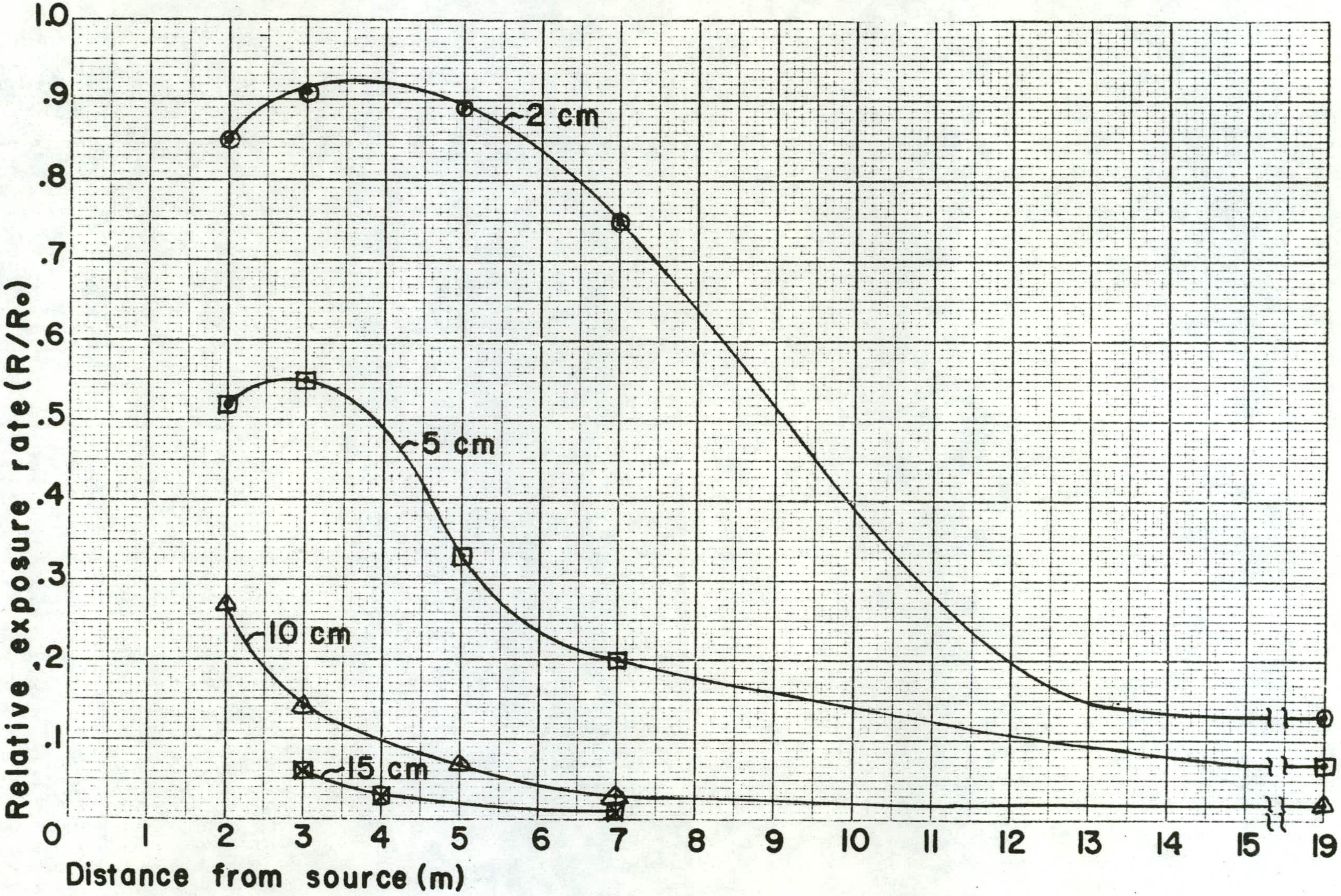

Fig. V. A. 5. Relative exposure rate as a function of distance at selected soil depths.

(Bogr), Opuntia polyacantha (Oppo) and Sporobolus cryptandrus (Spcr). For Bogr a 5 x 5 cm. area of the larger quadrat was used and an estimate was made of basal ground cover. For Oppo the number of lobes in the quadrat was counted and for Spcr, the number of tillers was counted. These data were used to calculate the density (plants/sq. meter), the coefficient of community and the frequency. Frequency was used to calculate the diversity index.

The diversity index was calculated using the equation

$$\overline{H} = -1.433 \sum_{i=1}^{n} p_i \ \ln (p_i)$$

where p_i was the probability (frequency) of sampling the $i^{\underline{th}}$ specie.

The coefficient of community (C.C.) was calculated from the equation

$$\text{C.C.} = \frac{C}{A+B-C}$$

where A was the number of species in the control macroplot, B was the number of species in the exposed macroplot and C was the number of species shared by the control and treated macroplots.

Weekly phenological data were recorded starting one week before the initiation of irradiation and continuing throughout the growing season. The grasses were scored using the following scale: 0 = dormant or dead; 1 = vegetative; 2 = flower stalk emergence; 3 = anthesis; 4 = seed formation; 5 = seed mature; 6 = seed dispersal; 7 = vegetative after seed maturation and dispersal; 8 = dormant or dead. The forbs and shrubs were scored using the following scale: 0 = dormant or dead; 1 = vegetative; 2 = flower bud formation; 3 = flower; 4 through 8, same as for the grasses.

In August a visual estimate was made of the Bogr biomass (standing live plus attached standing dead) in each microplot. Results were standardized by comparison with clipped plots outside the gamma field.

At selected times during the year, a black and white photograph was taken of a section of each microplot group. The tripod was placed at marked locations each time so that a time sequence was recorded showing progressive changes throughout the year. The same procedure was used at less frequent intervals using both regular Ectachrome and Aero Infra-red Ectachrone to determine the effectiveness of the Aero Infra-red for early prediction of radiation damage.

Results

General Effects and Appearance:

The time of initiation of irradiation coincided with the early growth period of the plant community. During normal spring growth the community experienced a period of relatively slow increase in biomass followed by a period of much faster increase which corresponded to rising air temperatures. The increased growth rate continued until available moisture became limiting. In the gamma field near the source the most noticeable immediate effect was the lack of growth of all the plants even though death was not apparent. Individuals of the various species present seemed to exist without progress in phenological development. Two to four weeks after the initiation of irradiation, the individuals at the higher exposure levels began to die as evidenced by the disappearance of chlorophyll in the plants, while individuals at somewhat lower exposure levels remained green but failed to grow. This process continued at about the same rate in both the chronic and spring sectors for two to three weeks after termination of irradiation of the spring sector, indicating a delay in the expression of radiation damage. The spring irradiated sector stabilized within three to four weeks following termination of irradiation while the process of delayed growth, with some eventual death, continued in the chronically irradiated sectors. The exposure rate resulting in complete lethality within six weeks after termination of irradiation for the spring exposure sector was approximately 185 R/hr.

By September the chronically exposed sectors could be divided into zones as follows:

(1). Complete lethality with almost no standing dead due to lack of early growth. This zone extended from macroplots 1 through 2 (one to three meters) with an exposure rate greater than 315 R/hr.

(2). Complete lethality with many species making some growth before death but without development beyond the vegetative stage. This zone extended from macroplots 3 through 5 (three to six meters) with an exposure rate greater than 68 R/hr.

(3). A transition zone with nearly normal vegetative growth and with some individuals of many species showing normal but delayed phenological development. The outer boundary of this zone varied with species but for the more resistant ones the zone extended from macroplots 6 through 8 (six to nine meters) with an exposure rate greater than 18 R/hr. For more sensitive species the zone extended to macroplot 15 (20.5 meters) with an exposure rate greater than 0.72 R/hr.

(4). A zone in which the methods used did not detect any significant changes.

The first two zones can be seen in Fig. V. A. 6. which shows the control sector on the lower left and one chronic sector on the lower right. The control sector shows the normal vegetative pattern. The chronic sector shows standing dead only although some species made considerable growth before death occurred. Just to the right of the irradiator the first two macroplots in chronic sector 3 show essentially no standing dead material (zone 1).

Diversity Index:

The diversity index ratio (diversity index of an exposed plot divided by the average diversity index of all control plots) is plotted in Fig. V. A. 7. These data indicated that the short grass plant community was

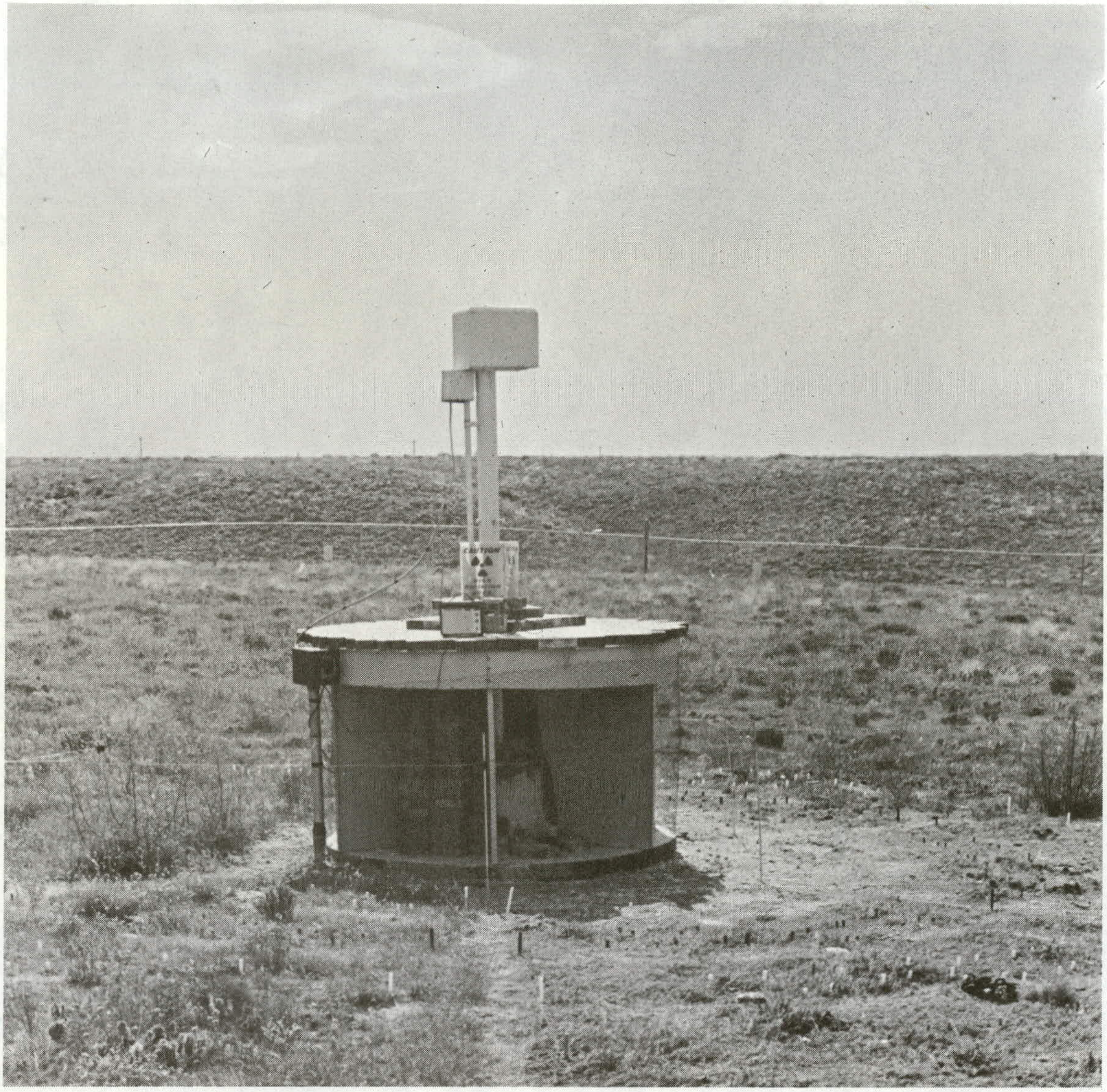

Fig. V. A. 6. Grassland plant community four months after initiation of chronic gamma irradiation. Control (shielded) sector is at lower left and chronic sectors are in lower right portion of photograph.

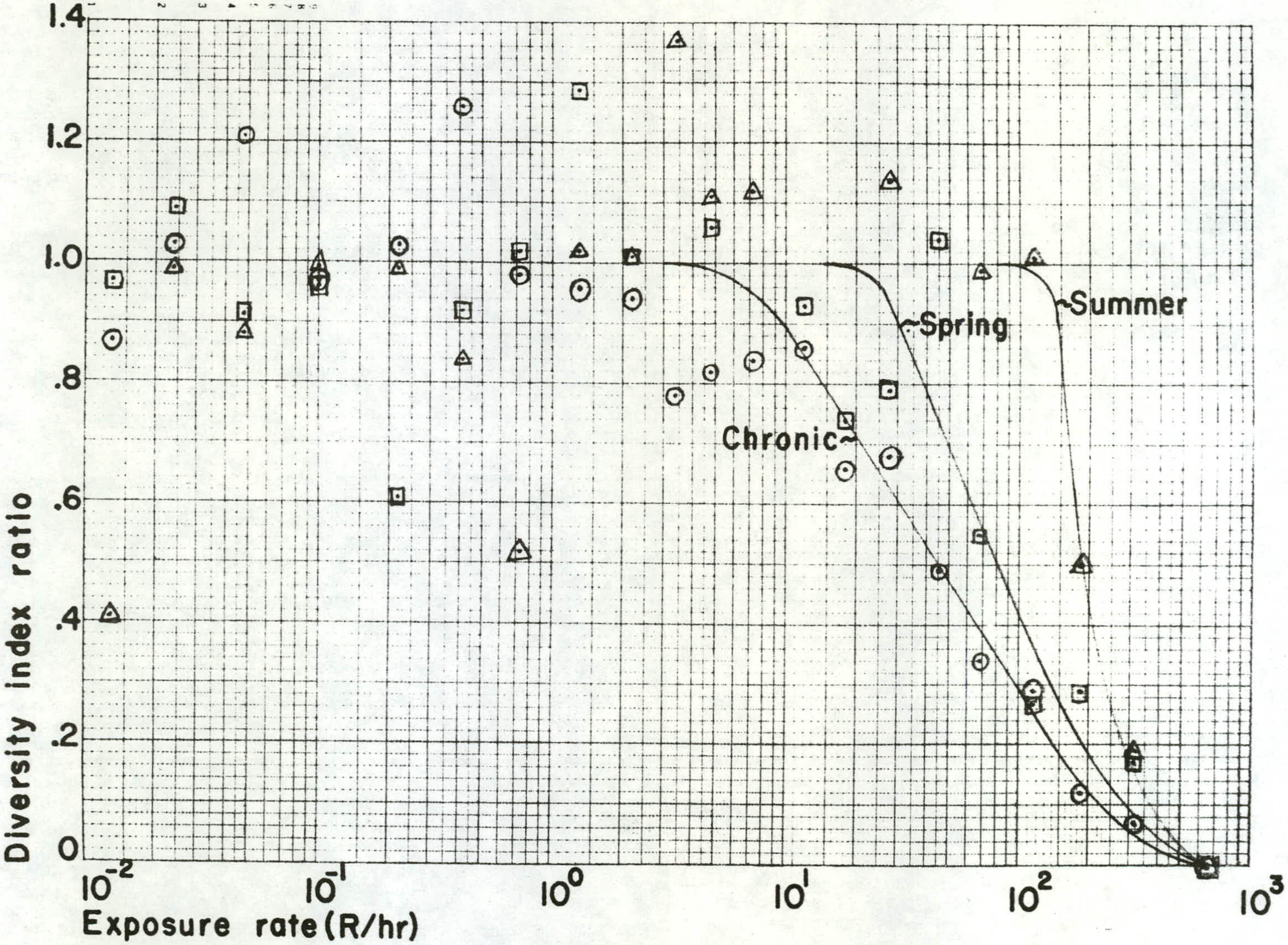

Fig. V. A. 7. Diversity index ratio as a function of exposure rate.

more sensitive to ionizing radiation in the spring than in the summer. The exposure rate necessary to reduce the diversity index ratio to 50 percent of normal for the spring exposure was about 72 R/hr compared to 190 R/hr for the summer exposure. The slopes of the curves reflect the differences in the exposure rates which resulted in complete kill to the exposure rates in which there were no detectable effects. For the spring sector this extended from macroplots 2 through 12 (315 to 3.4 R/hr) and for the summer sector this extended from macroplots 2 through 5 (315 to 68 R/hr).

The exposure rate necessary to reduce the diversity index ratio to 50 percent of normal in the chronically irradiated sector was 45 R/hr. The negative slope of the curve extended from macroplots 2 through 13 (315 to 2.2 R/hr). The total exposure necessary to reduce each exposed sector to 50 percent of its normal value was: summer, 142 kR; chronic, 78 kR; and spring, 55 kR.

Coefficient of Community:

The coefficient of community data are plotted in Fig. V. A. 8. These data also indicate that the short grass plant community is more sensitive to ionizing radiation in the spring than in the summer. The exposure rate that was necessary to reduce the coefficient of community values to 50 percent of normal for the spring exposure was 135 R/hr compared to 220 R/hr for the summer. The negative slope extended from macroplots 2 through 4 (315 to 115 R/hr) for the spring irradiated sector and from macroplots 2 through 3 (315 to 185 R/hr) for the summer irradiated sector. In the chronically exposed sector, the exposure rate necessary to reduce the coefficient of community to 50 percent of normal was 63 R/hr. The negative slope extended from macroplots 2 through 6 (315 to 45 R/hr). The total exposure necessary to reduce each exposed sector to 50 percent of its normal value was: summer, 164 kR; chronic, 109 kR; and spring, 104 kR.

A comparison of the coefficient of community and diversity index ratio data indicated that the diversity index ratio was a more sensitive indicator of radiation effects on the short grass plant community than the coefficient of community.

Phenology:

One of the most sensitive indicators of radiation damage to individuals of a given species seems to be the phenological index. The normal individual moves through various stages in its life form from dormancy to vegetative to reproductive to vegetative to dormancy. Exposure to ionizing radiation at exposures less than lethal apparently delays this progression at somewhat lower exposures and stops this progression at somewhat higher exposures. For Bogr the lowest exposure that delayed development was 10 R/hr and the lowest exposure that stopped development was 100 R/hr (Fig. V. A. 9.). For Oppo the lowest exposure that delayed development was 1 R/hr and the lowest exposure that stopped development was 10 R/hr (Fig. V. A. 10.). For <u>Tradescantia occidentalis</u> (Troc), the lowest exposure that delayed development was 0.1 R/hr and the lowest exposure that stopped development was 1 R/hr (Fig. V. A. 11.). These species illustrate

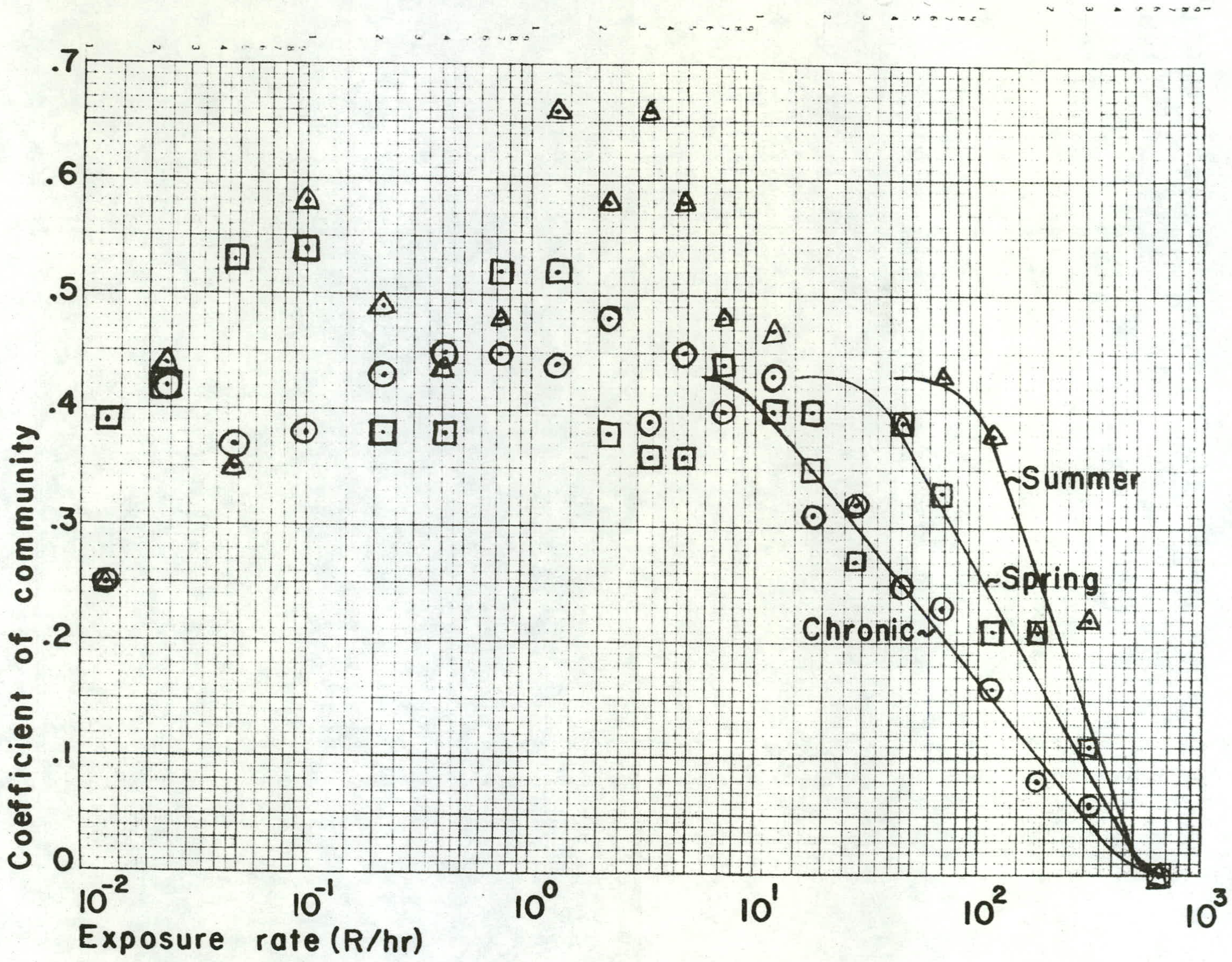

Fig. V. A. 8. Coefficient of community as a function of exposure rate.

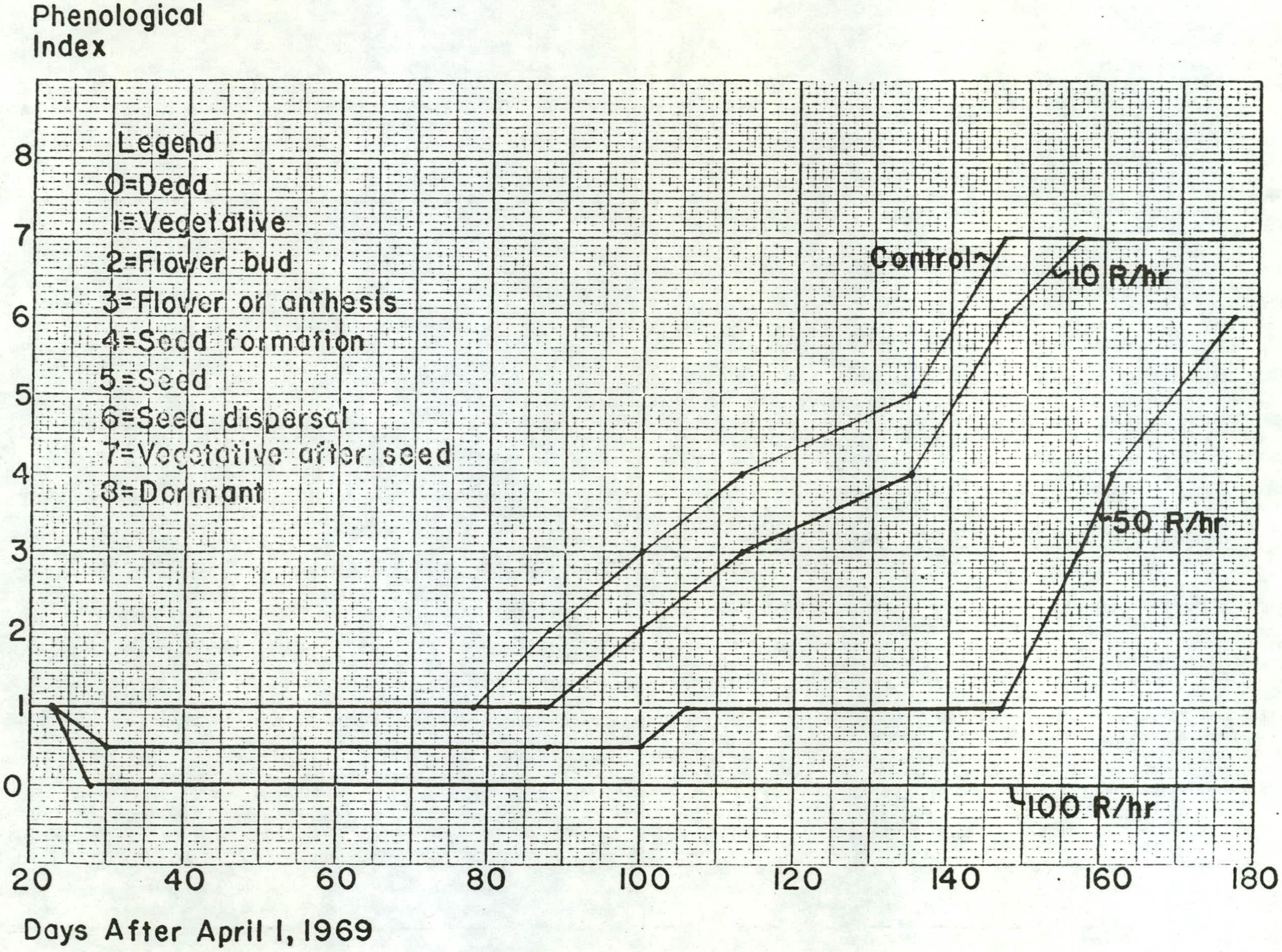

Fig. V. A. 9. Phenological index of Boutelona gracilis as a function of time for selected exposure rates.

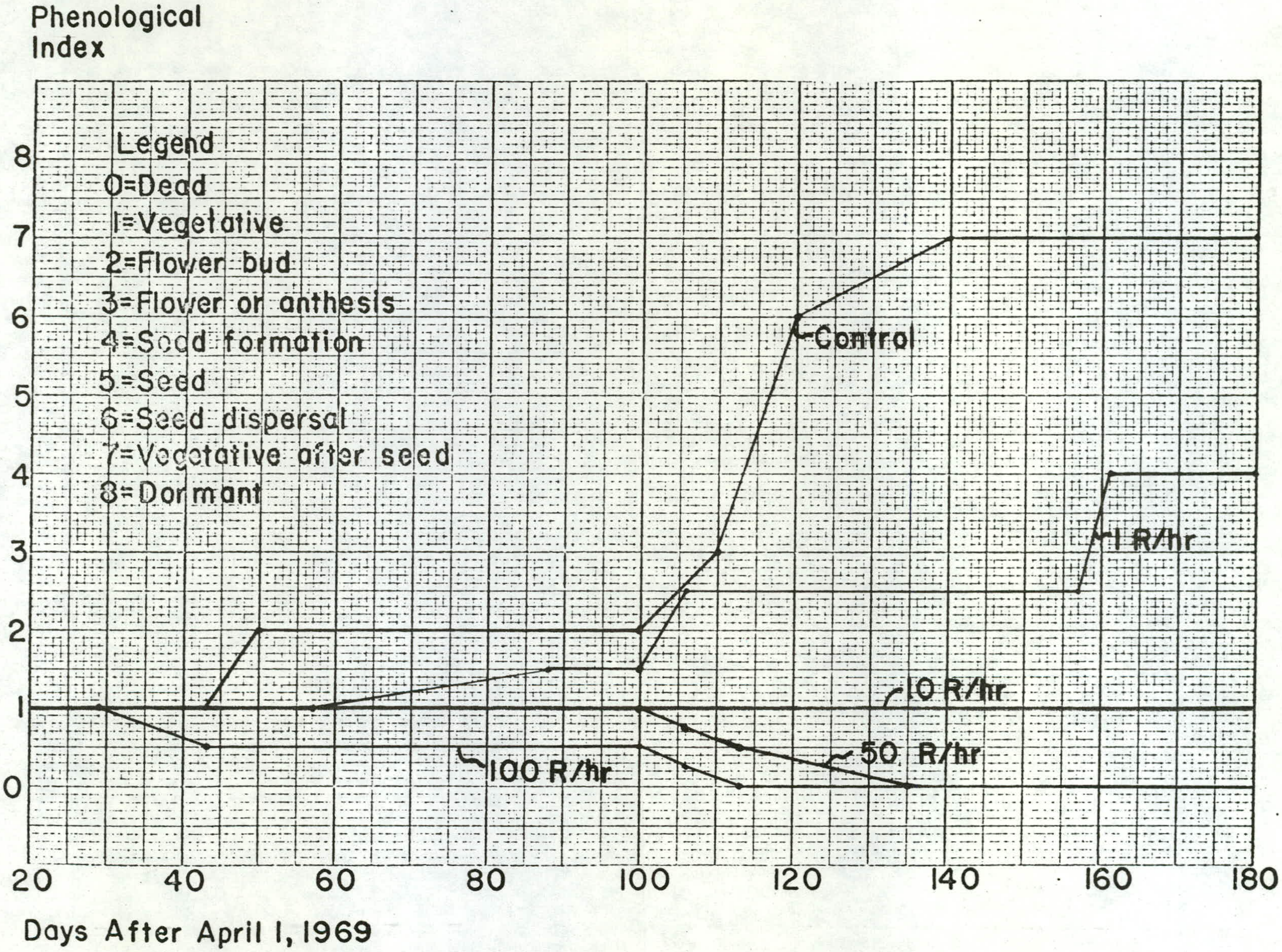

Fig. V. A. 10. Phenological index of Opuntia polyacantha as a function of time for selected exposure rates.

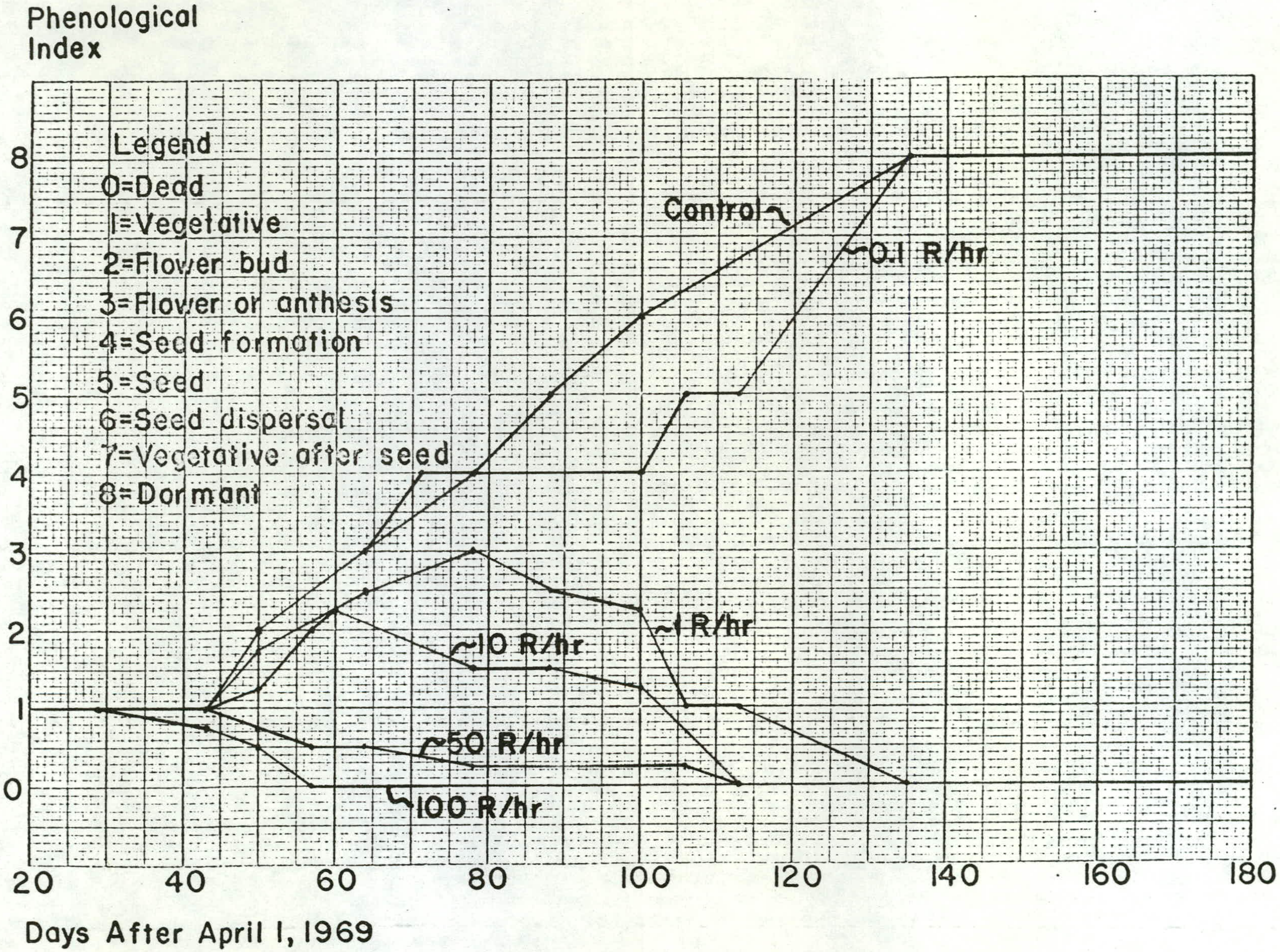

Fig. V. A. 11. Phenological index of Tradescantia occidentalis as a function of time for selected exposure rates.

the general effect on all species present in the short grass plant community and cover a ragne from a fairly resistant species (Bogr) through a moderately resistant species (Oppo) to a relatively sensitive species (Troc). Based on the phenological index, Tradescantia occidentalis appeared to be the most sensitive species in the short grass stand in our sampling area.

Bouteloua gracilis Biomass:

From an economic and relative abundance standpoint, blue gramma is the most important species in the short grass plant community. In mid-August a visual estimate was made of the biomass of blue gramma in all sectors and the data for the spring, summer and chronically irradiated sectors are plotted in Fig. V. A. 12. There was a significant reduction in biomass in the chronically irradiated sectors with an exposure rate of 16 R/hr giving a 50 percent reduction in yield. The negative slope extended from macroplots 6 to 9 (45 to 12 R/hr). There was a significant reduction in biomass in the sector irradiated in the spring with an exposure of 66 R/hr resulting in a 50 percent reduction in yield. The negative slope extended from macroplots 4 through 6 (115 to 45 R/hr). The total exposure for the chronically irradiated sectors at the 50 percent reduction level was 48 kR and for the spring irradiated sector it was 51 kR. The initiation of irradiation of the summer exposed sector occurred after most of the vegetative growth had taken place and there was no detectable effect on the yield of this sector.

Summary:

A short grass plant community was exposed to gamma irradiation. The results indicated that although some species in the community were relatively sensitive to ionizing radiation, the structure of the community was relatively insensitive. Compared to other plant communities, the short grass plant community appears to be among the most resistant of any studied to date (Table V. A. 2.). The data have not been processed sufficiently to be directly comparable but a subjective comparison does indicate general similarities or differences.

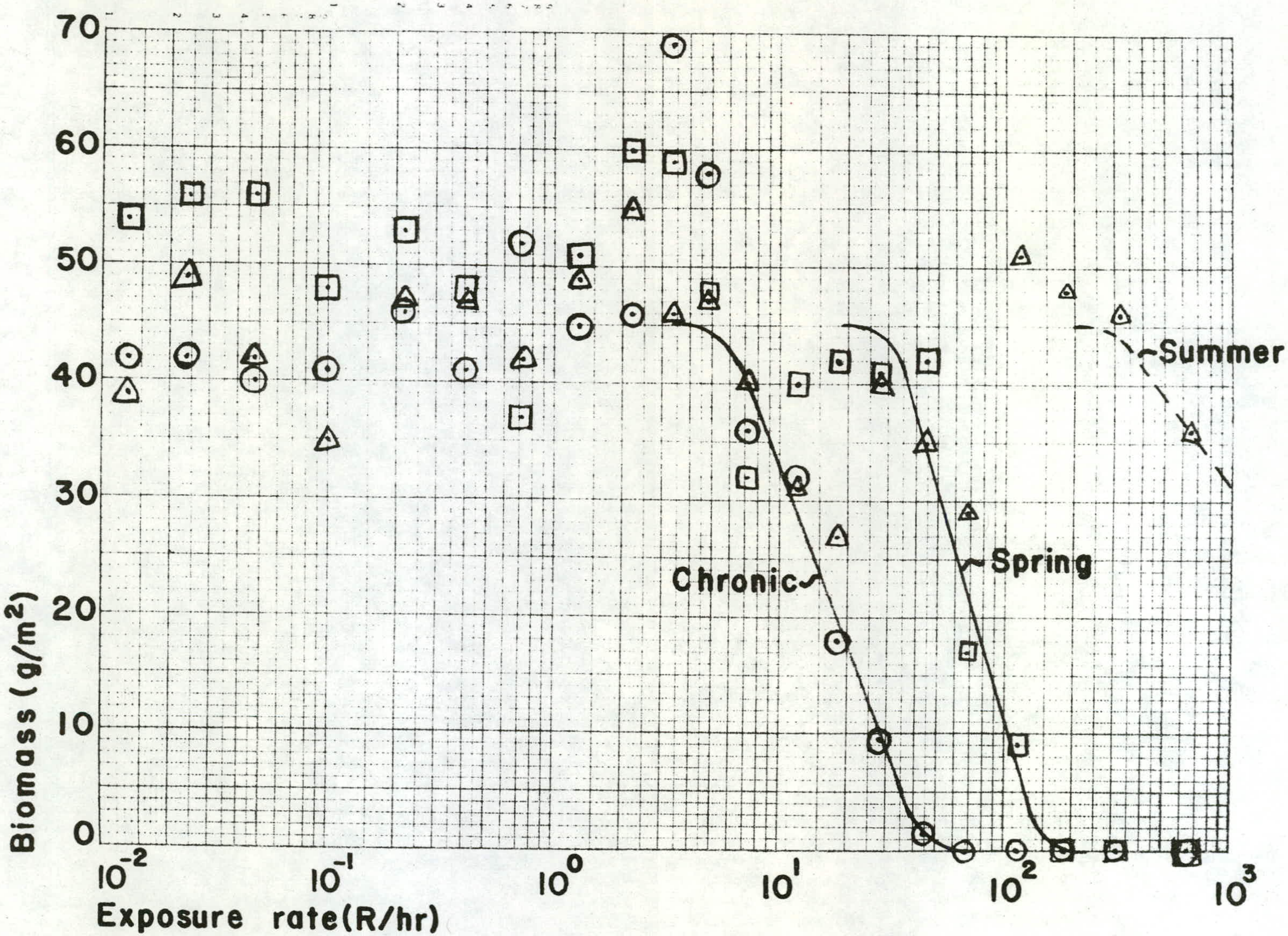

Fig. V. A. 12. Biomass of Bouteloua gracilis as a function of exposure rate.

Table V. A. 2. Summary of D_{50} Values and Comparison of Radiation Sensitivities of Plant Communities.

	Diversity Index			Coefficient of Community		
Community Type	Chronic	Spring	Summer	Chronic	Spring	Summer
Short Grass	45 R/hr	72 R/hr	190 R/hr	63 R/hr	135 R/hr	220 R/hr
	78 kR	55 kR	142 kR	109 kR	104 kR	164 kR
First Year-Old Field[1]	40 R/hr					
Second Year-Old Field[1]	50 R/hr					
Oak-Pine[2]						
1st yr.	8 R/hr					
2nd yr.	5 R/hr			5 R/hr		
3rd yr.	5 R/hr			3 R/hr		
Herbaceous Rock Outcrop[3]	40 kR					
Old Field[4]		60 kR			60 kR	

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[1] Woodwell, G. M. and J. K. Oosting. 1965. Effects of Chronic Gamma Irradiation on the Development of Old Field Plant Communities. Radiation Botany. 5: 205-222.

[2] Woodwell, G. M. and A. L. Rebuck. 1967. Effects of Chronic Gamma Radiation on the Structure and Diversity of an Oak-Pine Forest. Ecological Monographs. 37: 53-69.

[3] McCormick, J. F. 1967. Effects of Ionizing Radiation on a Pine Forest. p. 78-87. In D. J. Nelson and F. C. Evans (Ed.). Symposium on Radioecology. CONF-670503. U. S. Atomic Energy Commission, Division of Technical Information Extension, Oak Ridge, Tennessee.

[4] Miller, G. L. 1968. The Influence of Season on the Radiation Sensitivity of an Old Field Community. Ph.D. Dissertation. University of North Carolina, Chapel Hill. 249 p.

V. B. Radiation Effects on the Arthropod Community

L. L. Cadwell and F. W. Whicker

Ionizing radiation in the grassland ecosystem is certain to affect plant and animal communities at several trophic levels. The interactions of populations at all levels are, in part, responsible for the structure of both communities. Therefore, a study of consumer organisms should aid in the interpretation of radiation effects on the plant community and vice versa. The various grassland arthropods provide a practical means of investigating higher trophic levels within a radiation field of limited size.

The radiation source (originally 8750 Ci of ^{137}Cs) is located centrally in the study area. Six pie-shaped treatment sectors emanate from the source. The treatment sectors occupy about 45° each and are separated by 15° buffer zones which are partially shielded. Irradiation of the sectors is controlled by the placement of lead bricks near the source. The exposure rate ranges from 650 r/hr at 2 meters from the source to 7.8×10^{-3} r/hr at 50 meters for sectors under treatment. One sector serves as a control and is shielded at all times, two sectors receive chronic irradiation and one each received spring (April), summer (July), and late fall (December) treatment.

During March and early April permanent ground-level pit-fall traps were installed in each of the six treatment sectors. The traps were located along the mid-line radius of each sector in order to minimize the capture of arthropods that may move from the low exposure buffer zones into the treatment areas. One trap was placed mid-way between each of 22 consecutive vegetative sampling microplots along the radius with an additional trap beyond the last microplot.

Each pit-fall trap consists of a 4½ inch diameter circular core 4 inches deep. The core is lined with a short section of P.V.C. pipe which provides permanent support for the walls. During the trapping operation one-pint tin cans inserted into the core serve as collection vessels for the arthopods. Weatherproof masonite collars with beveled outer edges are placed over the traps to bridge the gap from the soil surface to the rim of the collection vessel. When the traps are not in use, the collars are removed and replaced with masonite covers.

Trapping was begun soon after the source was raised in early April and continued at 2-3 week intervals through September. Snow and freezing temperature in early October ended trapping for the year. A one-day trapping period was used for the first few trappings, but was later extended to two days.

A lack of familarity with arthropod identification and taxonomy necessitated sacrificing and preserving specimens for later classification. The contents of each trap were emptied into appropriately labeled shell vials containing formalin. The vials were returned to the laboratory where all specimens were counted and indexed. Insects were identified by comparing type specimens with the reference collection maintained by the Colorado State University Entomology Department. When only a few individuals of a particular taxonomic group were collected, they were identified only to family. More abundant types were classified to genus. Some spiders were sent to specialists for identification.

Indexing, counting and identification of insects for the first seven trapping periods (through early July) has been completed to date. Although specimens of several families and many genera have been collected, only a few taxa were abundant enough to have been sampled consistently with the trapping method used. The common families collected, in order of decreasing abundance, were Formicidae (ants), Carabidae (ground beetles), Tenebrionidae (darkling beetles) and Scarabaeidae (lamellicorn beetles). Ants were by far the most abundant insects collected. An estimated 75 percent of all ants collected were western harvester ants (Pogonomyrmex occidentalis). The total number of ants collected on each trapping date increased steadily with the warming trend from early spring through midsummer.

Trapping during the first two months (April and May) following initiation of irradiation showed average numbers of ants collected in chronic, spring (irradiated for the month of April only) and control sectors nearly the same. In June and early July, the number of ants collected in the chronically irradiated sectors dropped to about half the number collected in spring irradiated and control sectors. This trend, with a two-month lag period after initiation of irradiation suggests some secondary response to ionizing radiation.

In late October and early November counts were made of numbers of galls occurring on rabbitbrush (Chrysothamnus nauseosus) within each treatment sector. The galls are thought to have been formed by one of the gall midges (family Cecidomyiidae). Since the gall-forming insects have not yet been identified, treatment effects cannot be discussed in terms of the insect's life history. However, the data in Table V.B.1 suggest that eggs may have been deposited prior to or during the April irradiation period. Galls first appeared farther from the source (at a lower exposure rate) in the April irradiation sector than in either of the control sectors. As might be expected, gall formation in the chronic irradiation sectors was successful only at considerable distances from the source where the exposure rate is low. The first gall appearance in the summer sector (irradiated for the month of July) occurred about the same distance from the source as in the control sectors. Perhaps gall formation was nearly complete or larvae had entered more resistant stages by mid-summer. Although not all exposure levels were represented by plants, thresholds for gall formation for chronic, spring and summer exposures were 0.4, 7.2 and 28.0 r/hr, respectively. Living Chrysothamnus without galls appeared nearer the source than the first plant with galls in all treatment sectors. Apparently, plant death was not responsible for lack of gall formation, but plant damage rather than killing of eggs or larvae could have been responsible for the absence of galls in high exposure zones.

Table V.B.1. First occurrence of living *Chrysothamnus nauseosus* and associated midge galls for four treatment types, 1969

Observation Date	Treatment	Sector	Distance from source to first living plant (m)	Exposure rate at first living plant (r/hr)	Distance from source to first gall (m)	Exposure rate at first gall (r/hr)
10-23	Control	1	2.5	1.0*	7.5	0.1*
11-6	Control	6	1.5	2.9*	2.5	1.0*
11-4	Spring	4	6.5	45	10.8	7.2
11-6	Summer	5	3.5	185	6.5	28
11-4	Chronic	2	9.6	12	22.3	0.4
11-4	Chronic	3	13.5	3.4	22.3	0.4

*Exposure in control sectors due to scattered radiation only.

VI. LIST OF PUBLICATIONS

The following reports on work wholly or partially supported under AEC Contract AT (11-1)-1156 have been published or prepared for publication (the recent reprints and pre-prints accompany this report):

Hanson, W. C., F. W. Whicker, and A. H. Dahl. 1963. Iodine-131 in the thyroids of North American deer caribou: comparison after nuclear tests. Science 140: 801-802. (COO-1156-2)

Hanson, W. C., A. H. Dahl, F. W. Whicker, W. M. Longhurst, V. Flyger, S. P. Davey, and K. R. Greer. 1963. Thyroidal radioiodine concentrations in North American deer following 1961 - 1963 nuclear weapons tests. Health Physics 9: 1235-1239. (COO-1156-4)

Whicker, F. W., E. E. Remmenga, and A. H. Dahl. 1965. Factors influencing the accumulation of I-131 in Colorado deer thyroids following 1961 - 1962 nuclear weapons tests. Health Physics 11: 293-296. (COO-1156-8)

Whicker, F. W., G. C. Farris, A. H. Dahl, and E. E. Remmenga. 1965. Factors influencing the accumulation of fallout Cs-137 in Colorado mule deer. Health Physics 11: 1407-1414. (COO-1156-10)

Whicker, F. W. 1965. Factors influencing the accumulation of fallout cesium-137 in mule deer. Ph.D. Dissertation. Colorado State University, Fort Collins. 230 p. (COO-1156-11)

Farris, G. C. 1965. Strontium-90 in antlers and selected bones of Colorado mule deer. M.S. Thesis. Colorado State University, Fort Collins. 83 p. (COO-1156-12)

Whicker, F. W., G. C. Farris, and A. H. Dahl. 1967. Concentration patterns of Sr-90, Cs-137, and I-131 in a wild deer population and environment, p. 621-633. In B. Aberg and F. P. Hungate (Ed.) Radioecological Concentration Processes, Pergamon Press, New York. (COO-1156-13).

Whicker, F. W., R. A. Walters, and A. H. Dahl. 1967. Fallout radionuclides in Colorado deer liver. Nature 214: 511-513. (COO-1156-14)

Whicker, F. W., G. C. Farris, and A. H. Dahl. 1966. Radioiodine concentrations in Colorado deer and elk thyroids during 1964-65. J. Wildlife Mgmt. 30(4): 781-785. (COO-1156-16)

Farris, G. C., F. W. Whicker, and A. H. Dahl. 1967. Effect of age on radioactive and stable strontium accumulation in mule deer bone, p. 93-102. In J. M. A. Lenihan, J. F. Loutit, and J. H. Martin (Ed.) Strontium Metabolism, Academic Press, London. (COO-1156-17)

Whicker, F. W., G. C. Farris, and A. H. Dahl. 1968. Wild deer as a source of radionuclide intake by humans and as indicators of fallout hazards, p. 1105. In W. S. Snyder (Ed.) Radiation Protection, Pergamon Press, New York. (COO-1156-18)

Remmenga, E. E. and F. W. Whicker. 1967. Sampling variability in radionuclide concentrations in plants native to the Colorado Front Range. Health Physics 13: 977-983. (COO-1156-19)

Whicker, F. W. and C. M. Loveless. 1968. Relationships of physiography and microclimate to fallout deposition. Ecology 49(2): 363-366. (COO-1156-20)

Nelson, W. C. and F. W. Whicker. 1969. Cesium-137 in some Colorado game fish, 1965-66, p. 258-265. In D. J. Nelson and F. C. Evans (Ed.). Symposium on Radioecology. CONF-670503. U. S. Atomic Energy Commission, Division of Technical Information Extension, Oak Ridge, Tennessee. (COO-1156-21)

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Hakonson, T. E. and F. W. Whicker. 1969. Uptake and elimination of cesium-134 by mule deer, p. 616-622. In D. J. Nelson and F. C. Evans (Ed.). Symposium on Radioecology. CONF-670503. U. S. Atomic Energy Commission, Division of Technical Information Extension, Oak Ridge, Tennessee. (COO-1156-24)

Hakonson, T. E. 1967. Tissue distribution and excretion of ^{134}Cs in the mule deer. M. S. Thesis. Colorado State University, Fort Collins. 121 p. (COO-1156-25)

Farris, G. C. 1967. Factors influencing the accumulation of strontium-90, stable strontium, and calcium in mule deer. Ph.D. Dissertation. Colorado State University, Fort Collins. 189 p. (COO-1156-26)

Hakonson, T. E. and F. W. Whicker. Tissue distribution of radiocesium in the mule deer. Typewritten manuscript. 13 p. (COO-1156-27)

Hakonson, T. E. and F. W. Whicker. The contribution of various tissues and organs to total body mass in the mule deer. Typewritten manuscript. 8 p. (COO-1156-29)

Gist, C. S. 1969. Iodine-131 retention in mule deer. M. S. Thesis. Colorado State University, Fort Collins. 75 p. (COO-1156-31)

Markham, O. D. and F. W. Whicker. Radiation $LD50_{(30)}$ of pikas (Ochotona princeps) in the natural environment and in captivity. Am. Midland Naturalist. In press; Accepted July 30, 1969. (COO-1156-32)

Markham, O. D., F. W. Whicker, and R. M. Hansen. Radiation $LD50_{(30)}$ of Richardson ground squirrels. Health Physics. In press; Accepted December 11, 1969. (COO-1156-33)

Gallegos, A. F. 1969. Radiocesium kinetics in the components of a montane lake ecosystem. Ph.D. Dissertation. Colorado State University, Fort Collins. 342 p. (COO-1156-34)

Nagy, J. G., T. E. Hakonson, and K. L. Knox. 1969. Effects of food quality on food intake in deer. Trans. 34th North Am. Wild. and Natural Resources Conf. 34: 146-154.

VII. LIST OF ORAL PRESENTATIONS

The following papers representing work conducted under AEC Contract AT (11-1)-1156 have been presented orally at scientific meetings:

Whicker, F. W. and A. H. Dahl. 1963. Accumulation of fallout radionuclides in Colorado mule deer. Presented June 13, 1963 at the annual meeting of Health Physics Society. P/90. (COO-1156-3)

Dahl, A. H., F. W. Whicker, and G. C. Farris. 1964. A study of the food chain patterns of Sr-90, Cs-137, and I-131 in a mule deer population. Presented March 10, 1964 at the meeting on Radiation and Wildlife at the North American Wildlife Conference, Las Vegas, Nevada.

Farris, G. C. 1964. Strontium-90 concentrations in bones and forage plants. Presented April 24, 1964 at the AEC-ARMU Technical Conference at the University of New Mexico. P/1, Session IV. (COO-1156-6)

Farris, G. C., A. H. Dahl, and F. W. Whicker. 1964. Accumulation of Sr-90 in selected bones and forage plants of Colorado mule deer. Presented June 18, 1964 at the annual meeting of the Health Physics Society. P/131. (COO-1156-7)

Whicker, F. W., G. C. Farris, A. H. Dahl, and E. E. Remmenga. 1965. Factors influencing the accumulation of fallout Cs-137 in Colorado mule deer. Presented May 4, 1965 at the Battelle-Northwest Symposium on Radiation and Terrestrial Ecosystems. (COO-1156-10)

Whicker, F. W. 1965. Fallout radionuclides in mule deer. Presented August 9, 1965 at the Central Mountains and Plains Section Conference of the Wildlife Society.

Whicker, F. W., G. C. Farris, and A. H. Dahl. 1966. Concentration patterns of Sr-90, Cs-137, and I-131 in a wild deer population and environment. Presented at the Symposium on Radioecological Concentration Processes, April 25-29, 1966, Stockholm, Sweden. (COO-1156-13)

Farris, G. C., F. W. Whicker, and A. H. Dahl. Effect of age on radioactive and stable strontium accumulation in mule deer. Presented at the International Symposium on Some Aspects of Strontium Metabolism, May 5-6, 1966, Chapelcross, Scotland. (COO-1156-17)

Whicker, F. W., R. A. Walters, and A. H. Dahl. Fallout radionuclides in Colorado deer livers. Eleventh Annual Meeting, Health Physics Society, June 27-30, 1966, Houston, Texas. P/79.

Whicker, F. W., G. C. Farris, and A. H. Dahl. Wild deer as a source of radionuclide intake by humans and as indicators of fallout hazards. Presented at the First International Congress of IRPA, September 5-10, 1966, Rome, Italy. (COO-1156-18)

Nelson, W. C. and F. W. Whicker. Cesium-137 concentrations in some Colorado game fish, 1965-66. Presented at the Second National Symposium on Radioecology, May 15-17, 1967, Ann Arbor, Michigan. P/54. (COO-1156-21)

Farris, G. C., F. W. Whicker, and A. H. Dahl. Strontium-90 levels in mule deer and forage plants. Presented at the Second National Symposium on Radioecology, May 15-17, 1967, Ann Arbor, Michigan. P/42. (COO-1156-23)

Hakonson, T. E. and F. W. Whicker. Uptake and elimination of cesium-134 by mule deer. Presented at the Second National Symposium on Radioecology, May 15-17, 1967, Ann Arbor, Michigan. P/44. (COO-1156-24)

Hakonson, T. E. Uptake and elimination of cesium-134 by mule deer. Presented at the Institute of Arctic Biology, University of Alaska, College, Alaska, March 22, 1968.

Farris, G. C., F. W. Whicker, and A. H. Dahl. Factors influencing the accumulation of Sr-90, stable strontium and calcium in mule deer. Presented at the Thirteenth Annual Meeting, Health Physics Society, June 16-20, 1968, Denver, Colorado. P/114.

Whicker, F. W. and C. M. Loveless. Relationships of physiography and microclimate to fallout deposition. Presented at the AAAS-Ecological Society Meeting, June 24-29, 1968, Logan, Utah. P/36.

Gallegos, A. F. Curve fitting of biological models to ingrowth type equations. Presented April 26, 1969 at the Student Conference, American Nuclear Society, University of New Mexico, Albuquerque.

Gist, C. S. and F. W. Whicker. Radioiodine retention in mule deer. Presented May 9, 1969 at the AAAS-Colorado Wyoming Academy of Science Meetings, Colorado Springs, Colorado. P/204.

Gallegos, A. F. Radiocesium kinetics in a montane lake ecosystem. Presented May 10, 1969 at the AAAS-Colorado Wyoming Academy of Science Meetings, Colorado Springs, Colorado. P/240.

Whicker, F. W. Investigations in radioecology at Colorado State University. Presented June 6, 1969 at the Institute of Arctic Biology, University of Alaska, College.

Fraley, L. Response of a shortgrass plains community to ionizing radiation. Presented October 24, 1969 at the IBP Pawnee Site Research Seminar. Southern Colorado State College, Pueblo, Colorado.

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Hakonson, T. E. Concepts concerning radioactive materials and their relationship to ecology. Presented December 22, 1969 to the Kiwanis Club, Cottage Grove, Oregon.


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